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SOME CHARACTERISTICS OF UNITED STATES TEMPERATURES.

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[Harvard University, Jan. 3, 1922.]

Introduction.—The present is a fitting time to consider anew the essential characteristics of the temperatures of the United States, and this because the material available for study is now more abundant and better standardized than ever before. In the new *Atlas of American Agriculture,* which has been in preparation by the United States Department of Agriculture for some years, there is a division devoted to *Climate.* This climatic portion contains a *Temperature* section, with three subdivisions, dealing, respectively, with *Temperature, Frost and the Growing Season,* and *Sunshine and Wind.* The only portion of the Temperature Section thus far published in complete and final form is that on *Frost and the Growing Season.*[1] The whole subject of frost is here presented with a detail not hitherto attained in any other area of equal size anywhere in the world.[2] Several of the maps and diagrams which are later to be included in the *Sunshine and Wind* section have been given advance publication in the MONTHLY WEATHER REVIEW.[3] But up to the present time none of the other new charts from the *Temperature* section have been published in any form or discussed anywhere. By permission, and through the courtesy of Dr. O. E. Baker, under whose supervision the new *Atlas of American Agriculture* has been prepared, and of Mr. J. B. Kincer, who constructed many of the maps, and by permission of the Chief of the Weather Bureau, the present writer has been able to have sent to him such of the new charts as he desired to examine for the purpose of the accompanying article, and has been given the privilege of redrawing and of reproducing all of these charts. He is under very great obligations to Dr. Baker, not only for allowing the charts to be sent out of Washington, but also for having certain of them specially drawn, and in some cases for having photographs made of the originals.

The whole discussion of temperature for the new Atlas is extraordinarily complete, especially if the size of the area covered is considered. Furthermore, it puts our whole knowledge of temperature conditions in the United States for the first time upon a sound and thoroughly scientific basis. We now have standard temperature charts based upon homogeneous observations covering a uniform period. The unusual completeness of the new discussion may be judged by the list of charts and curves included.[4]

The immediate object of the *Atlas* being to benefit agricultural interests, the needs of that group were primarily in mind in planning the sections on climate. Hence, while all of the maps and curves are of importance, and will prove useful in a variety of investigations, there is naturally considerable detail which is not of immediate significance in a very general discussion like that here in hand. Hence reference is here made to such charts only as have a broad climatic significance. Those who are especially concerned with the more detailed matters of climate and crops will find abundant and most valuable material in the other charts which are listed below (Footnote 4), but are not otherwise referred to in the following discussion.

The larger temperature relations.—The larger facts regarding temperature are best seen on the world isothermal maps which show the course of the (sea-level) isotherms over the oceans as well as over the lands.[5] The isotherms show certain systematic deflections as they pass from ocean to ocean across North America. Thus, in the higher latitudes, there is a marked poleward deflection in the northeastern Pacific, and a more moderate equatorward deflection in northeastern North America. In middle and lower latitudes, *per contra,* there is an equatorward deflection as the isotherms ap-

[1] *Atlas of American Agriculture.* Prepared under the supervision of O. E. Baker, Agriculturist. Part II. *Climate.* Contribution from the U. S. Weather Bureau, Charles F. Marvin, Chief. Section 1. *Frost and the Growing Season.* By William Gardner Reed, assistant in agricultural geography, Office of Farm Management. Prepared under the joint direction of P. C. Day, climatologist, U. S. Weather Bureau, and O. E. Baker, agriculturist, Office of Farm Management. U. S. Department of Agriculture, Office of Farm Management, W. J. Spillman, Chief. fol. Washington, D. C., 1918 (Advance Sheet, 2). pp. 11, figs. 33.

[2] See R. DeC. Ward: Frost in the United States, *Geogr. Rev.*, vol. 7, 1919, pp. 339–344 (a review of the above).

[3] Joseph Burton Kincer: Sunshine in the United States, MO. WEATHER REV., vol. 48, 1920, pp. 12–17. Reviewed by R. DeC. Ward: A New Series of Sunshine Maps of the United States, *Geogr. Rev.*, vol. 10, 1920, pp. 339–341.

[4] The following list was contained in a letter from Mr. R. G. Hainsworth, head draftsman, dated Sept. 24, 1921.

Four 24 in. plates. Fig. A, an identification map showing the drainage, culture, and altitudinal tints. Fig. 2 shows the average daily summer temperature. Fig. 72 is a map showing the annual march of significant temperatures at selected stations. Fig. 86 shows, in the form of a graph, the daily minimum and maximum temperatures at selected stations.

Fourteen maps, 7½ by 11¼ inches. Twelve of these show the average monthly temperatures. Fig. 5 shows the average winter temperatures, December to February, inclusive. Fig. 7 shows the average annual minimum temperatures.

Sixty-five maps, 3½ by 5½ inches. Fig. 8 the lowest temperatures ever observed and the number of times in 20 years the lowest temperature was 6° or more below the average temperature: fig. 9, the number of times in 20 years the winter temperature was 9° or more below the average winter temperature: fig. 10, the number of times the maximum temperature was 32° or lower; fig. 11, the average annual number of days with the minimum temperature 32° or lower; fig. 13, the average daily maximum temperature for January; fig. 14, the average minimum temperature for January; fig. 15, the highest monthly mean temperature for January; fig. 16, the lowest mean monthly temperature for January. Corresponding maps are available for the 11 other months of the year.

Fig. 73 shows the average date when the mean daily temperature rises above 35°; fig. 74, the average date when the average daily temperature rises above 45°; fig. 75, the average date when the average daily temperature rises above 55°; fig. 76, the average date when the average daily temperature rises above 65°; fig. 77, the average date when the average daily temperature falls below 65°; fig. 78, the average date when the average daily temperature falls below 55°; fig. 79, the average date when the average daily temperature falls below 45°.

Figs. 81–84 show the mean daily temperature range for January, April, July, and October.

Fig. 1, a graph, shows the annual march of temperature and sunshine by means of monthly curves. An insert graph, fig. 85, shows the daily march of temperature (selected stations). Fig. 87, the last figure in the temperature section, shows graphs of thermograms.

[5] See, e. g., the *Challenger* charts, reproduced in *Atlas of Meteorology*, pls. 1, 3; text, pp. 7, 9.

proach the continent from the Pacific; a poleward looping as they enter the continent, and then another gentle equatorward trend as they approach the Atlantic. These deflections, similar to, but more marked than, those found in corresponding latitudes of Eurasia, result in a crowding of the isotherms on the eastern coasts of the northern continents, and a spreading apart on the eastern sides of the northern oceans. The opposite sides of the North Atlantic show this contrast at its best. "In western Europe, one may travel a thousand miles northward without finding so great a change of mean annual temperature as would be found in a voyage of half that distance along our eastern coast."[6]

These systematic isothermal deflections follow very closely, and are chiefly due to, the general flow of the great ocean currents. The spreading of the isotherms on the west coast of North America depends upon the equatorward-flowing cool return current in the lower latitudes, off the coast of California and of Mexico, and upon the poleward-flowing warm eddy which circles around the Bay of Alaska. On the east coast, the isotherms in the higher latitudes are carried equatorward by the cold Labrador Current, while, farther south, the warm Gulf Stream carries them poleward.

These mean annual sea-level world-isotherms represent approximately the conditions of spring and autumn. Comparing them with those for January and for July, the midwinter and midsummer months, it is seen that in the middle and higher latitudes the mean annual isotherms are a weak reproduction of those of January. In lower latitudes, on the other hand, the systematic deflections of the former resemble those of July. The cold winters of the central and northern interior may thus be said to control the course of the mean annual isotherms over the higher latitudes, while the hot summers of the southern portion of North America leave their mark on the course of the annual isotherms in the lower latitudes.

In comparison with the mean temperatures of the different latitudes, most of North America is too cold in winter (January). A district of abnormally low temperatures (20°–30° F. below the general mean for the latitude) centers over Hudson Bay and the adjacent lands. Another, of abnormally high temperatures (20° F. above the mean of the latitude), appears over the warm waters of the Bay of Alaska. Lying to leeward of this latter district, a considerable strip along the Pacific coast, extending from Alaska to as far south as southern California, is warmer than the means of its latitudes.[7] The isanomalies[8] are less marked in July. North America as a whole is somewhat warmer than the mean temperatures of its latitudes in July. The greatest plus departure (10° or more above normal) occurs over the western interior deserts of Nevada and Arizona. The regions of Hudson Bay and of Labrador, and the Pacific coast, are too cool. In the mean for the year, North America, with the exception of its west coast, is colder than normal for its latitudes.

Mean annual, monthly and seasonal isothermal charts (actual temperatures): General[9]—The fundamental isothermal charts are those for the year, the twelve months, and either the four seasons or the two opposite seasons of summer and winter. With the exception of the mean annual chart, this whole series has been constructed anew, on a uniform basic period, for the *Atlas of American Agriculture*. The new charts show actual temperatures, not reduced to sea-level. They supersede all other existing isothermal maps of the United States, and will, for years to come, remain the "standard set."

Mean annual temperatures.—Certain broad generalizations regarding the distribution of the mean annual temperatures over the United States are readily made.[10] With a wide range of latitude, with two flanking oceans on the east and west, and a warm gulf on the south, it is inevitable that the United States should show considerable differences of temperature between north and south, and between the narrow windward west coast and the interior. Roughly, east of the one hundred and fifth meridian the northern tier of States has 40°–50°; the central tier, 50°–60°; the southern tier, over 60°. The Lake Superior region has below 40°, and southern Florida and southeastern Texas, over 70°. The east-and-west course of the isotherms is modified by the Appalachian mountain system, where the lower temperature, due to elevation, is indicated by the equatorward deflection of the isotherms.

West of the one hundred and fifth meridian the chart is far from satisfactory, owing to the deficiency of observations over the mountains and plateaus. Temperatures over 70° are indicated in southwestern Arizona and southeastern California. Most of the northern portion of the plateau district (north of lat. 38° N.; and, in the southeastern part of the district, as far as lat. 35° N.) has 45°–50°. There is a decrease along the Pacific coast from 65° in the south to 50° in the north. Deflections and irregularities due to topography are especially marked over the southwestern interior. A comparison of the temperatures on the Pacific and the Atlantic coasts shows that these do not differ appreciably in middle and lower latitudes. In the north, however, the Pacific coast is distinctly the warmer. Thus, at latitude 45° on the Pacific, the mean annual temperature is between 50° and 55°; on the Atlantic it is between 40° and 45°. San Diego, Calif., and Charleston, S. C., on the other hand, both in the same latitude, have almost the same mean annual temperatures.

Midwinter and midsummer average temperatures.—The new series of charts showing the average monthly temperatures gives, for the first time, an accurate and detailed picture of the actual distribution of temperatures, month by month, over the United States. The isotherms are drawn for 5° intervals. For roughly two-thirds of the country, to the east of the Rocky Mountains, the isotherms run fairly smoothly and symmetrically, but show the effects of the Appalachian topography in the warping and local irregularities of many of the lines over that section. Over the western plateau and mountain area, on the other hand, there is much irregularity, close crowding, and difficulty in making any broad, accurate generalization. It is for this western area in particular that the

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[6] W. M. Davis: Elementary Meteorology, p. 66.

[7] Charles F. Batchelder: A New Series of Isanomalous Temperature Charts, Based on Buchan's Isothermal Charts, *Amer. Met. Journ.*, vol. 10, 1893–94, pp. 451–474. The charts are reproduced in the *Atlas of Meteorology*, pl. 2; text, p. 8.

[8] Departures from the mean temperature of the latitude.

[9] R. DeC. Ward: Bibliographic Notes on the Temperature Charts of the United States. Mo. WEATHER REV., vol. 49, 1921, pp. 277–280. In addition to the publications cited in the foregoing, and in a further paper by the present writer (A Short Bibliography of United States Climatology, *Journ. Geogr.*, vol. 17, 1918, pp. 137–144), reference may here be made to the following publications of the last 15 years which deal with temperature data:

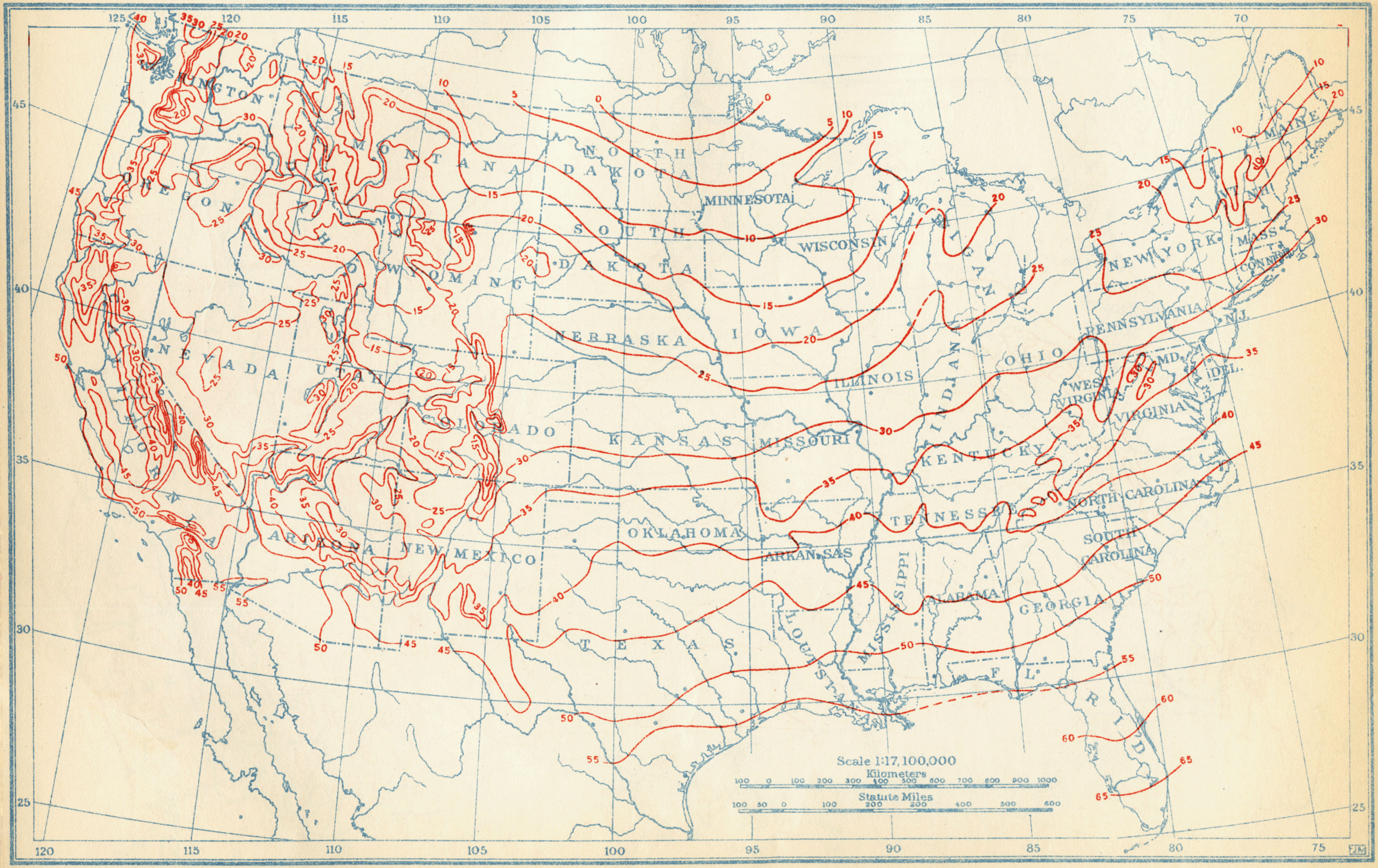
W. B. Stockman: Temperature and Relative Humidity Data, *Bulletin O*, U. S. Weather Bureau. 4to. Washington, D. C., 1905. Contains tables of maximum and minimum temperatures recorded at Weather Bureau stations in each month from the beginning of observations to the end of December, 1904; also the mean monthly and mean annual maximum and minimum temperatures, and charts showing the absolute *maxima and absolute minima*.

F. H. Bigelow: The Daily Normal Temperature and the Daily Normal Precipitation in the United States. *Bulletin R*, U. S. Weather Bureau. 4to. Washington, D. C., 1908. The daily normals are obtained by a process of smoothing. The monthly means are plotted: a curve is drawn through these twelve points, and the temperatures for each day are then scaled off.

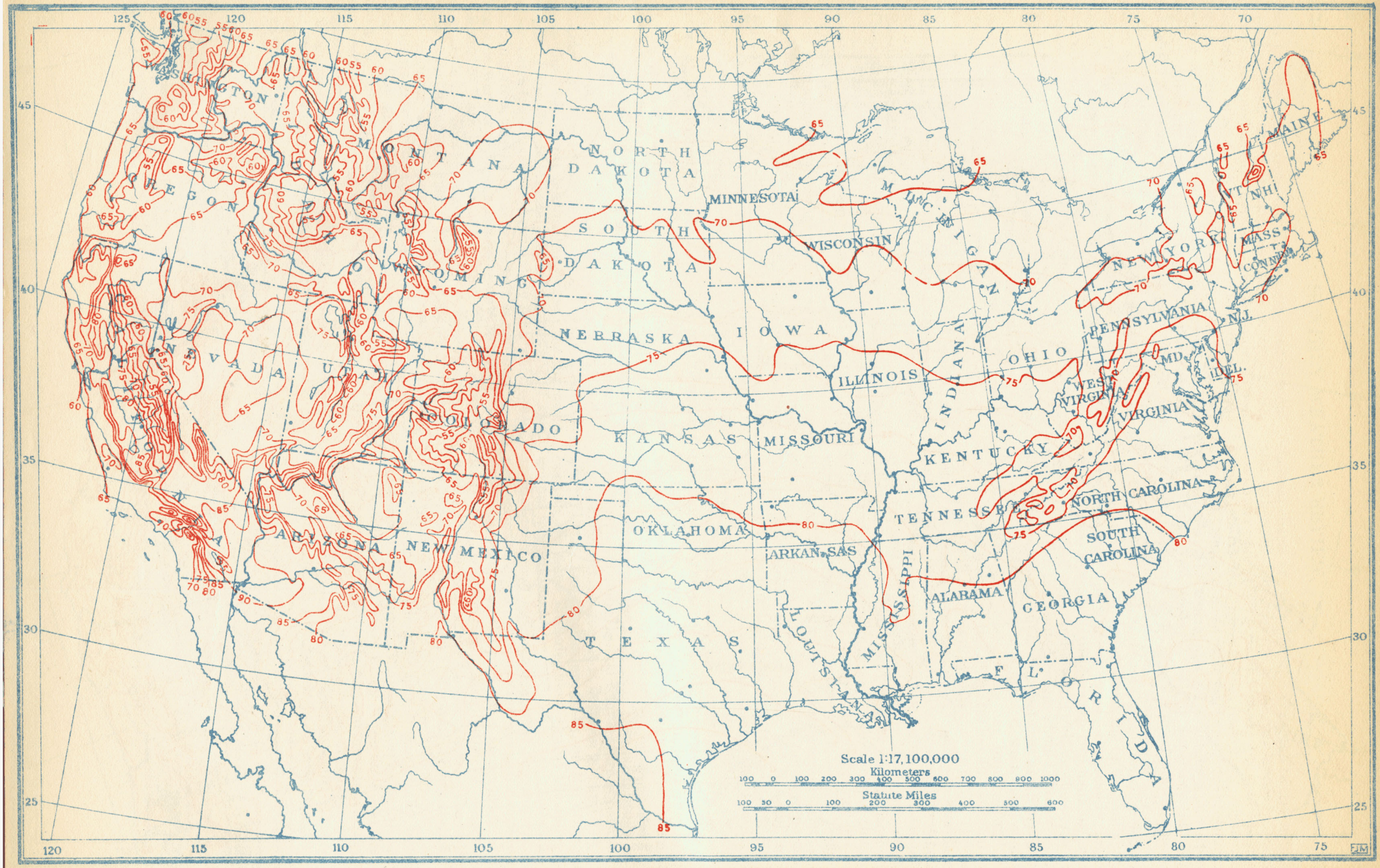
F. H. Bigelow: Report on the Temperatures and Vapor Tensions of the United States. *Bulletin S*. U. S. Weather Bureau. 4to. Washington, D. C., 1909. The statement on the title-page "reduced to a homogeneous system of 24 hourly observations for the 33-year interval 1873–1905" is somewhat misleading. The means are *not* all reduced to the same period of years. Homogeneous refers only to the reduction to *true* means.

[10] The latest chart of mean annual temperature is that included in the set of *Climatic Charts of the United States* (*U. S. Weather Bureau*.)

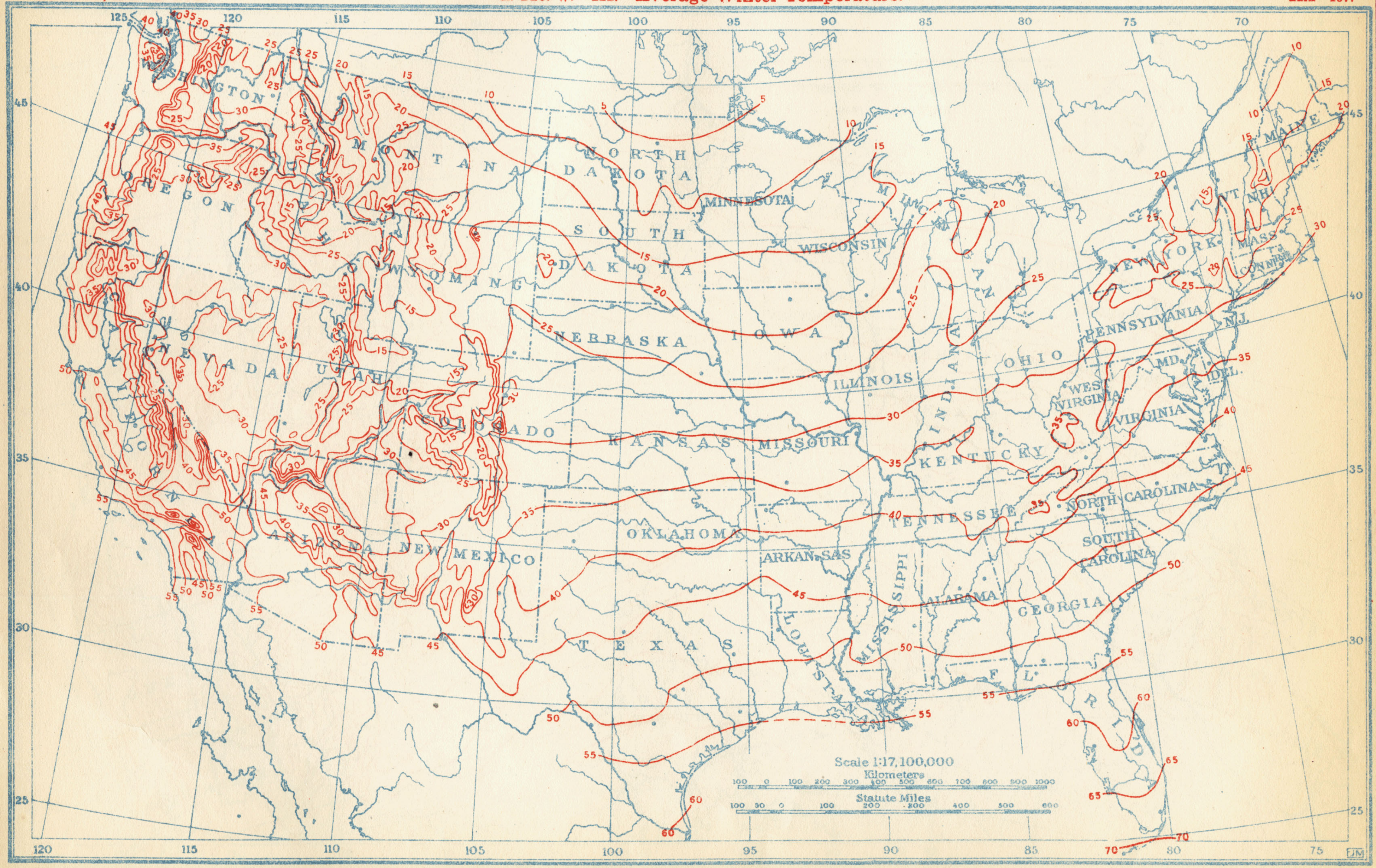
R. DEC. W. I.—Average Monthly Temperature for January.



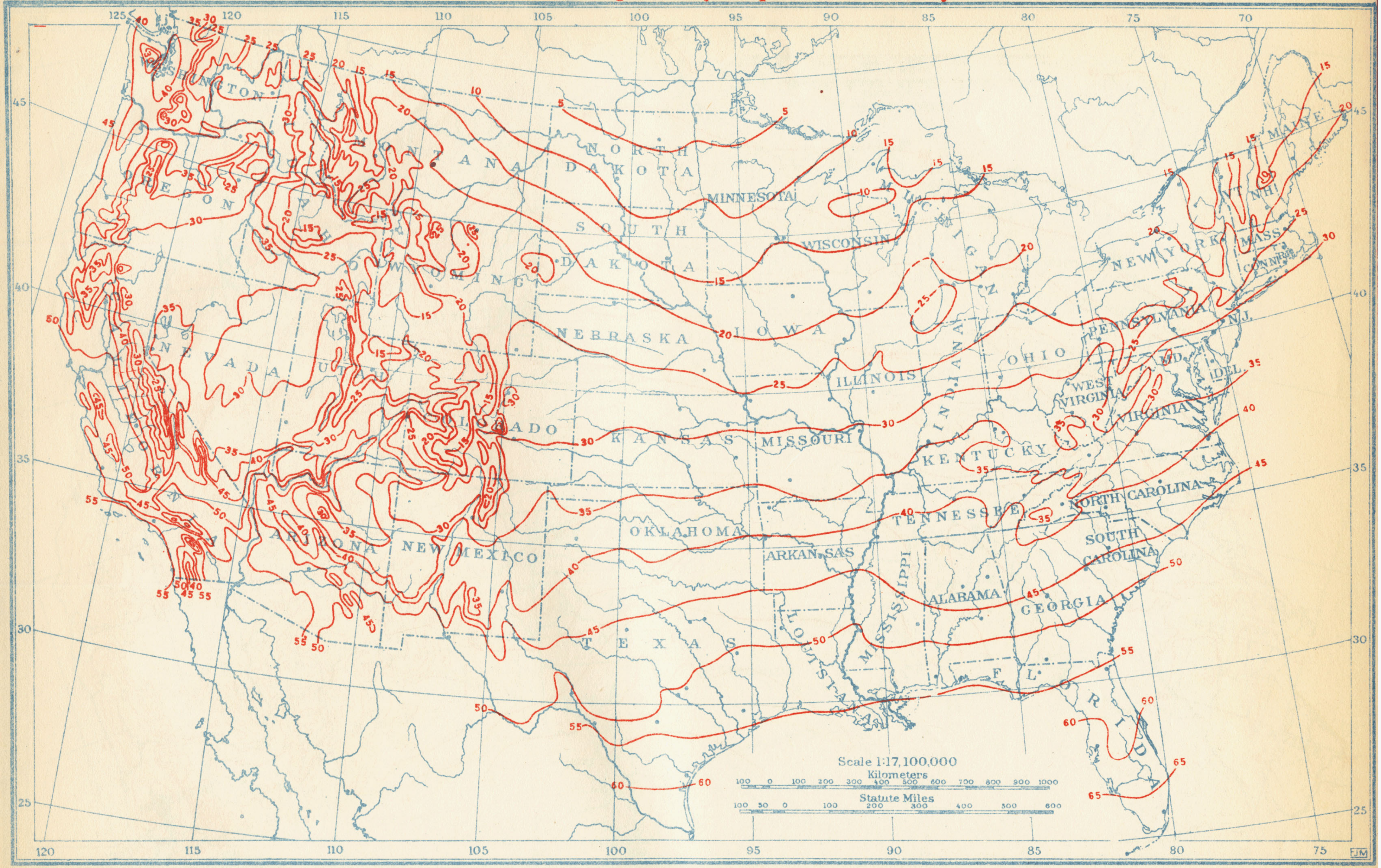
II.—Average Monthly Temperature for July.



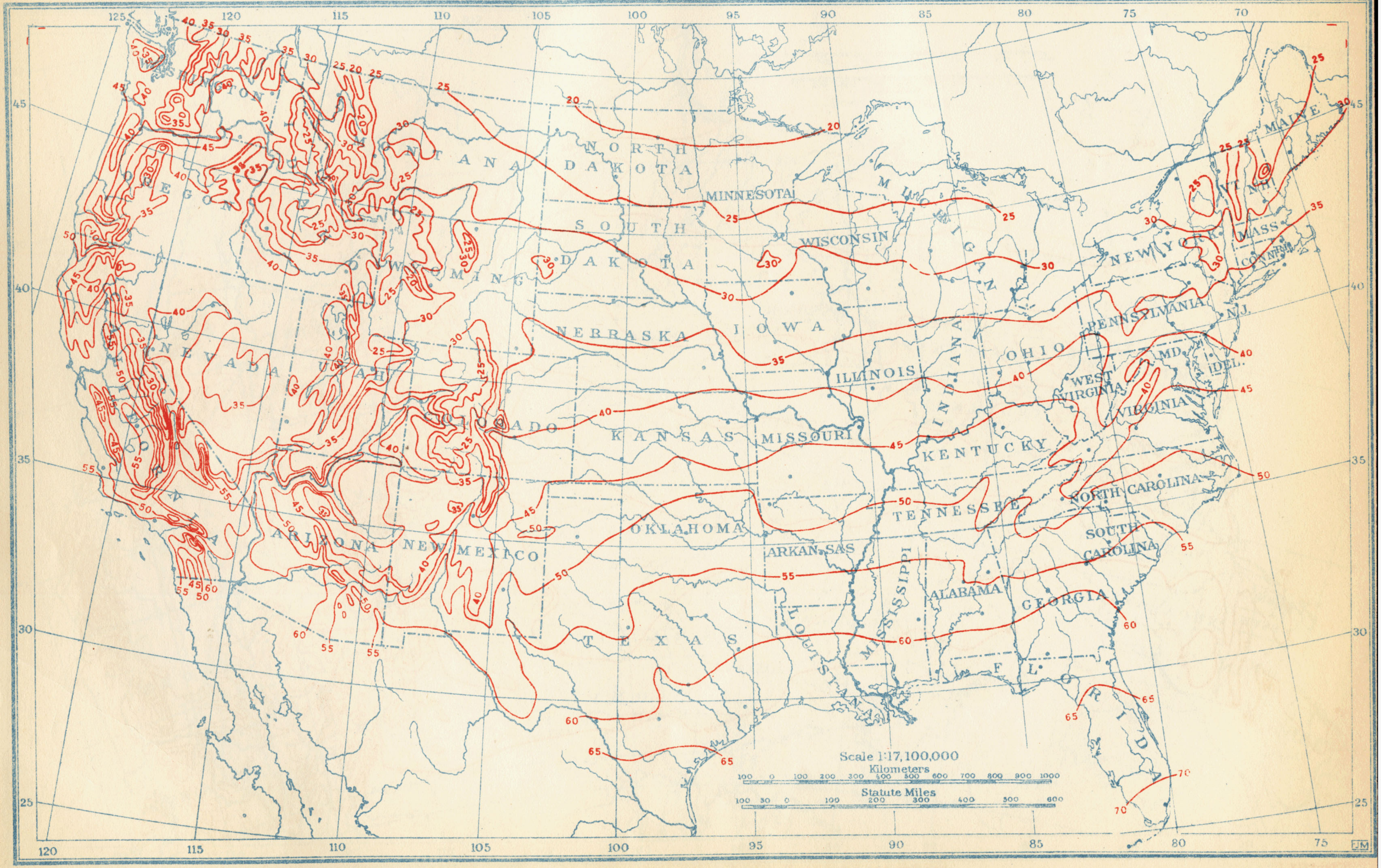
III.—Average Winter Temperature.



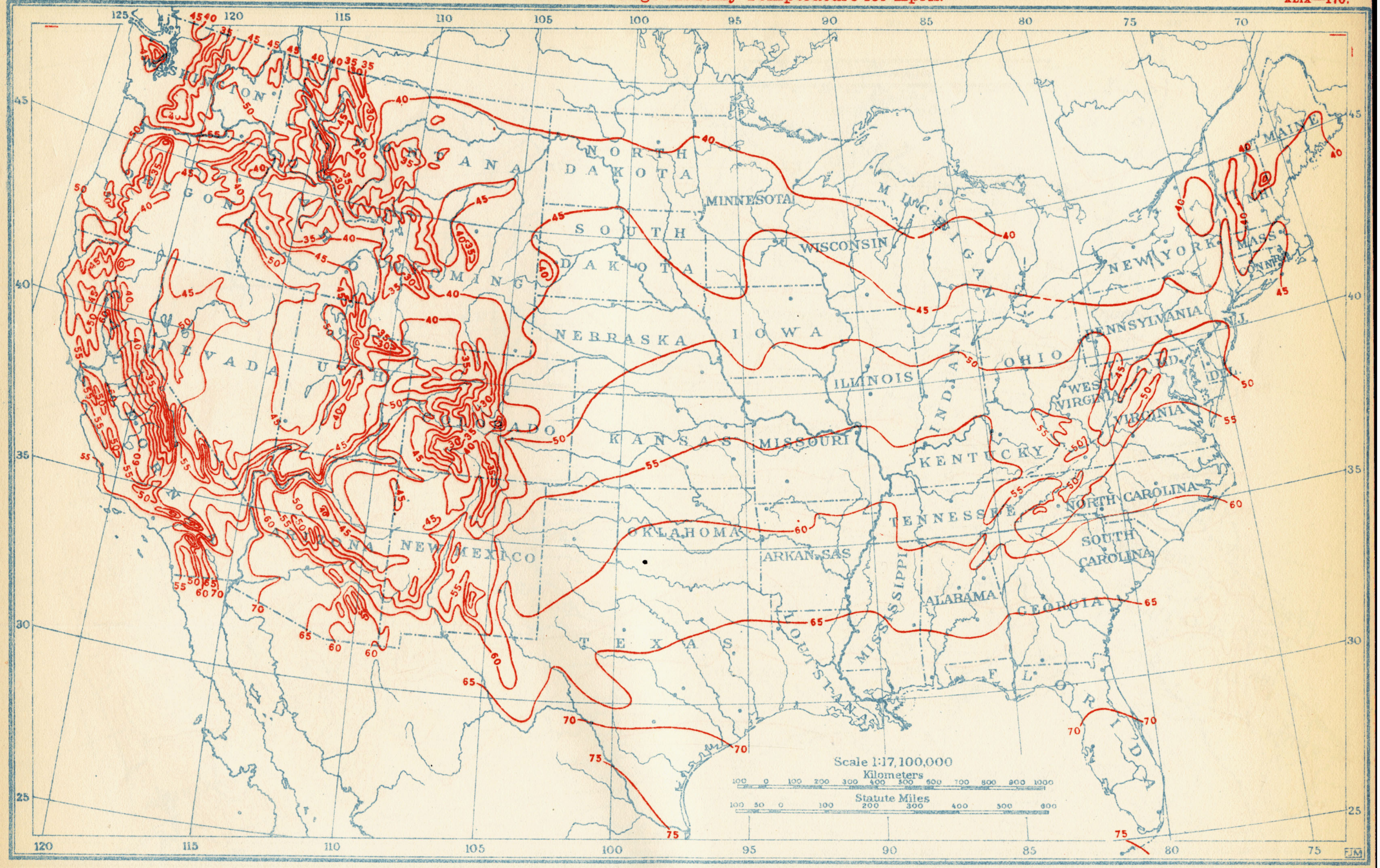
IV.—Average Monthly Temperature for February.



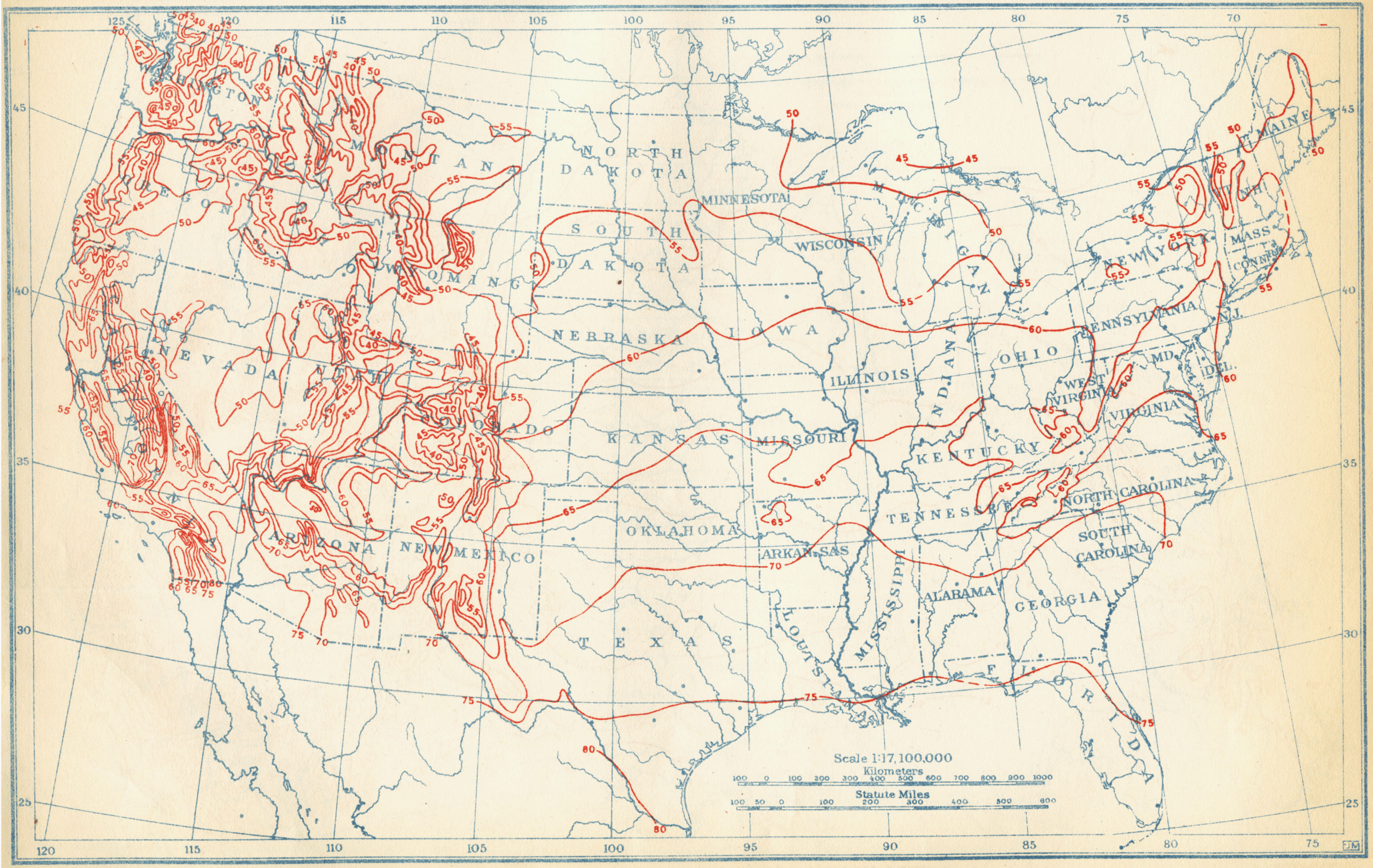
V.—Average Monthly Temperature for March.



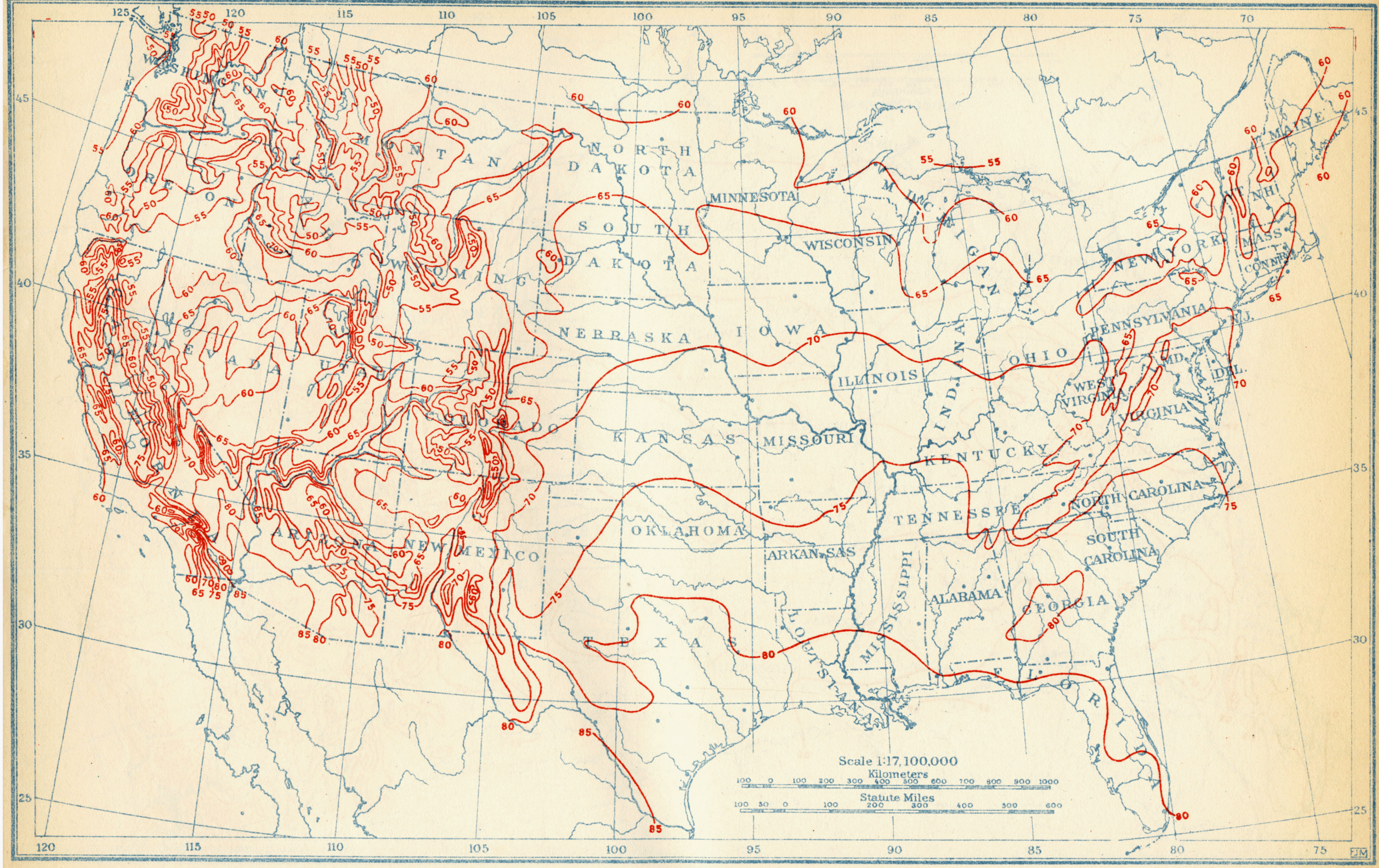
R. DEC. W. VI.—Average Monthly Temperature for April.



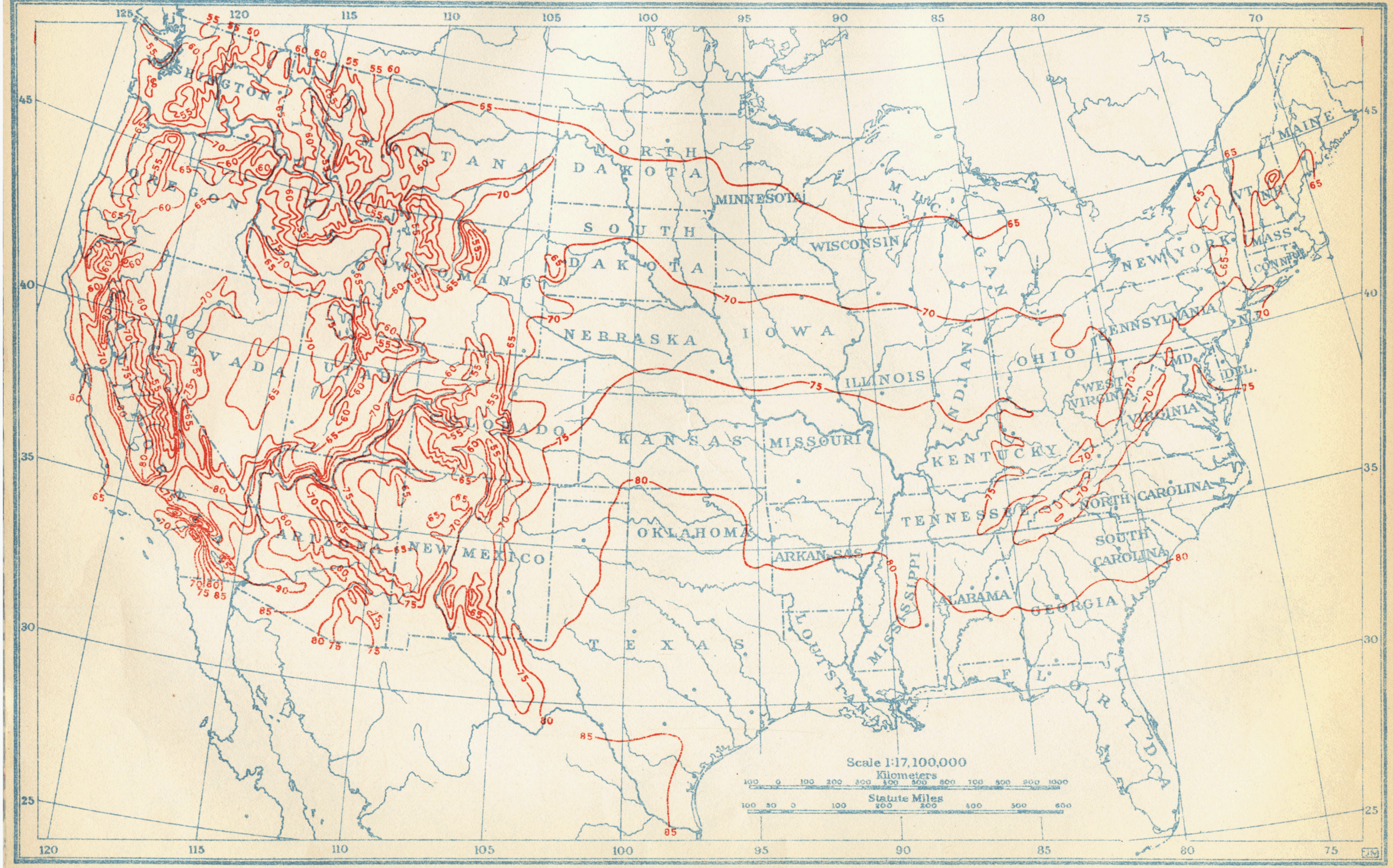
VII.—Average Monthly Temperature for May.



R. DEC. W. VIII.—Average Monthly Temperature for June.



R. DEC. W. IX.—Average Monthly Temperature for August.

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KANSAS
OKLAHOMA
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IOWA
MISSOURI
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OHIO
KENTUCKY
TENNESSEE
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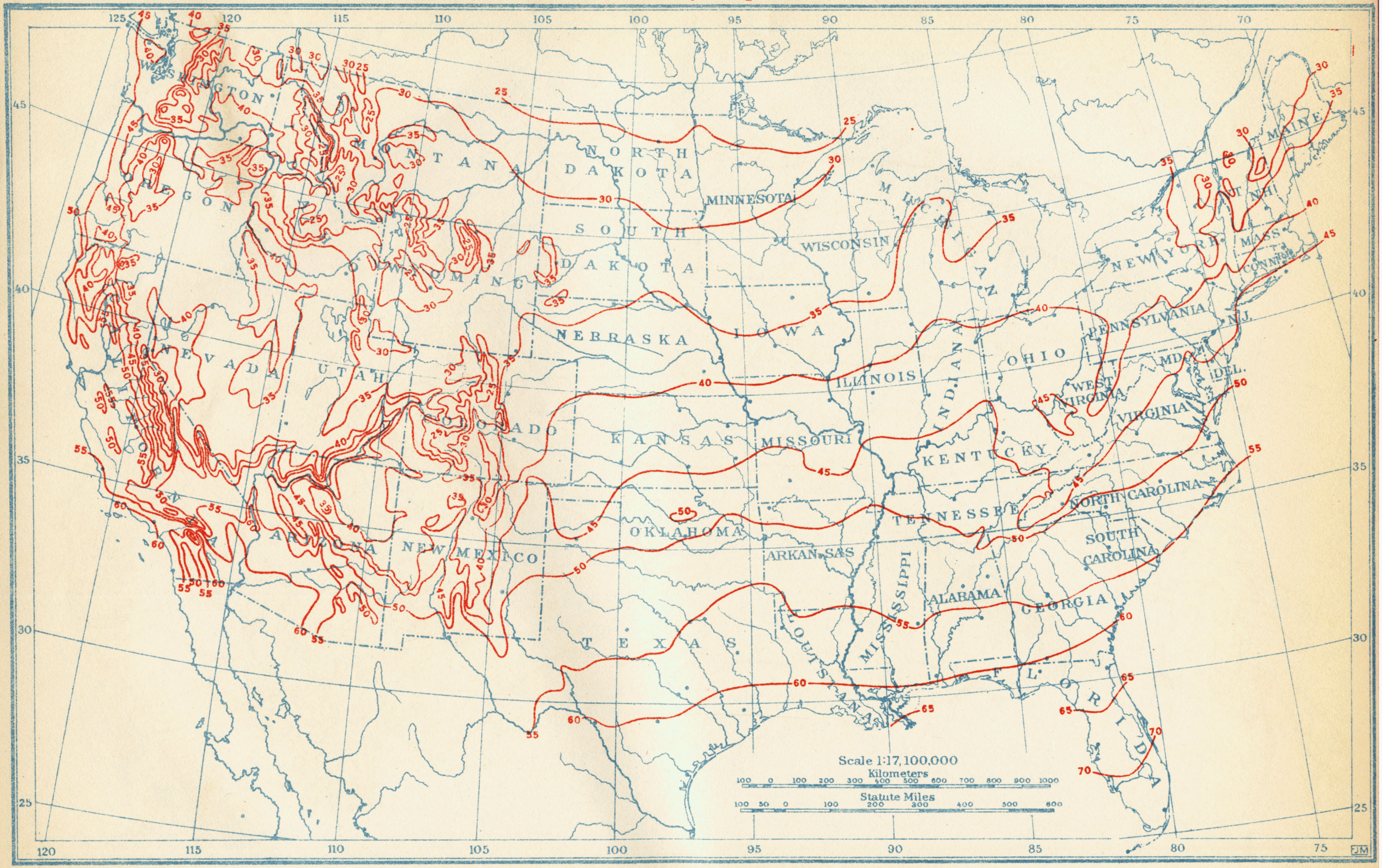
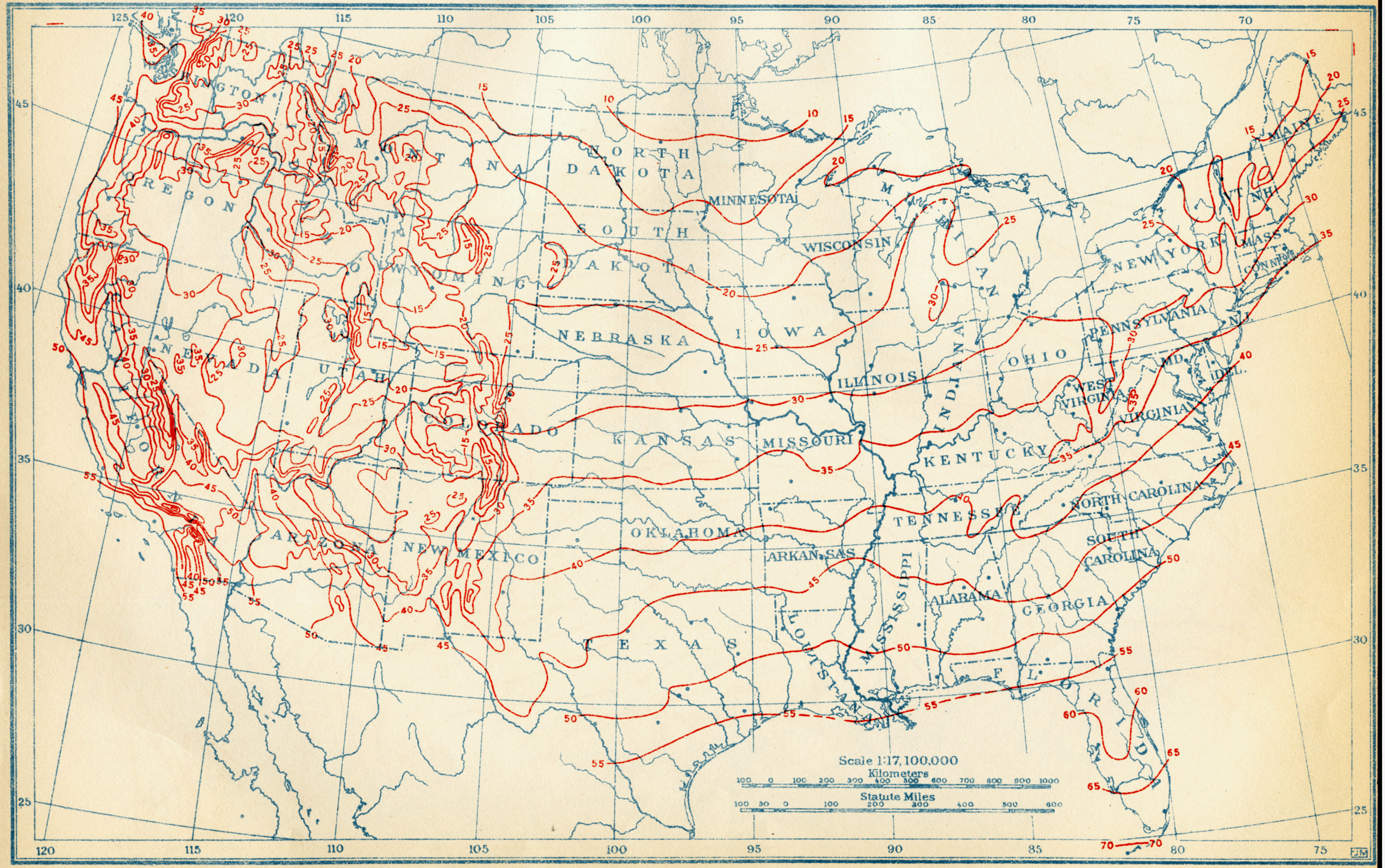
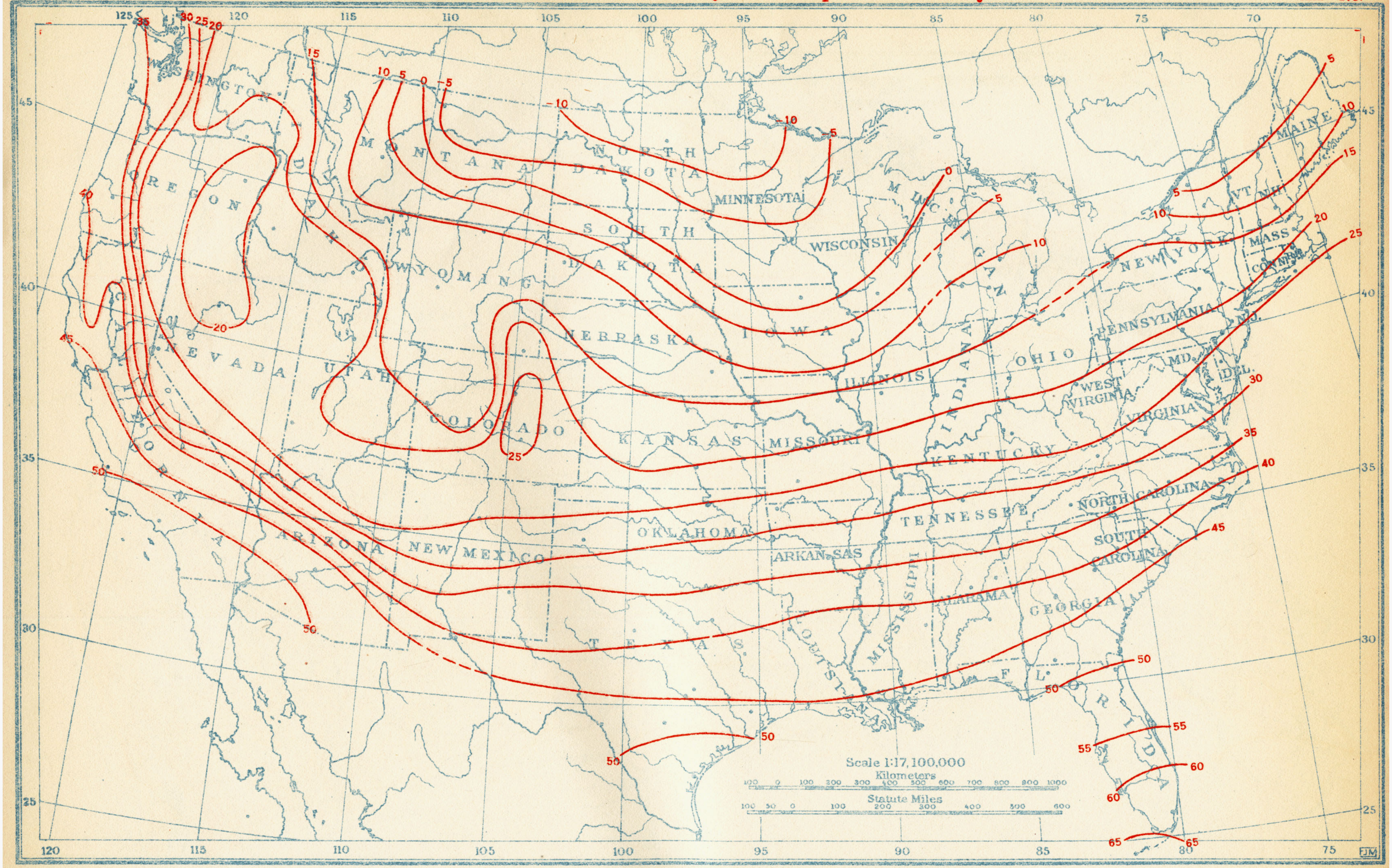
XI.—Average Monthly Temperature for October.

XII.—Average Monthly Temperature for November.



R. DEC. W. XIII.—Average Monthly Temperature for December.





Scale 1:17,100,000
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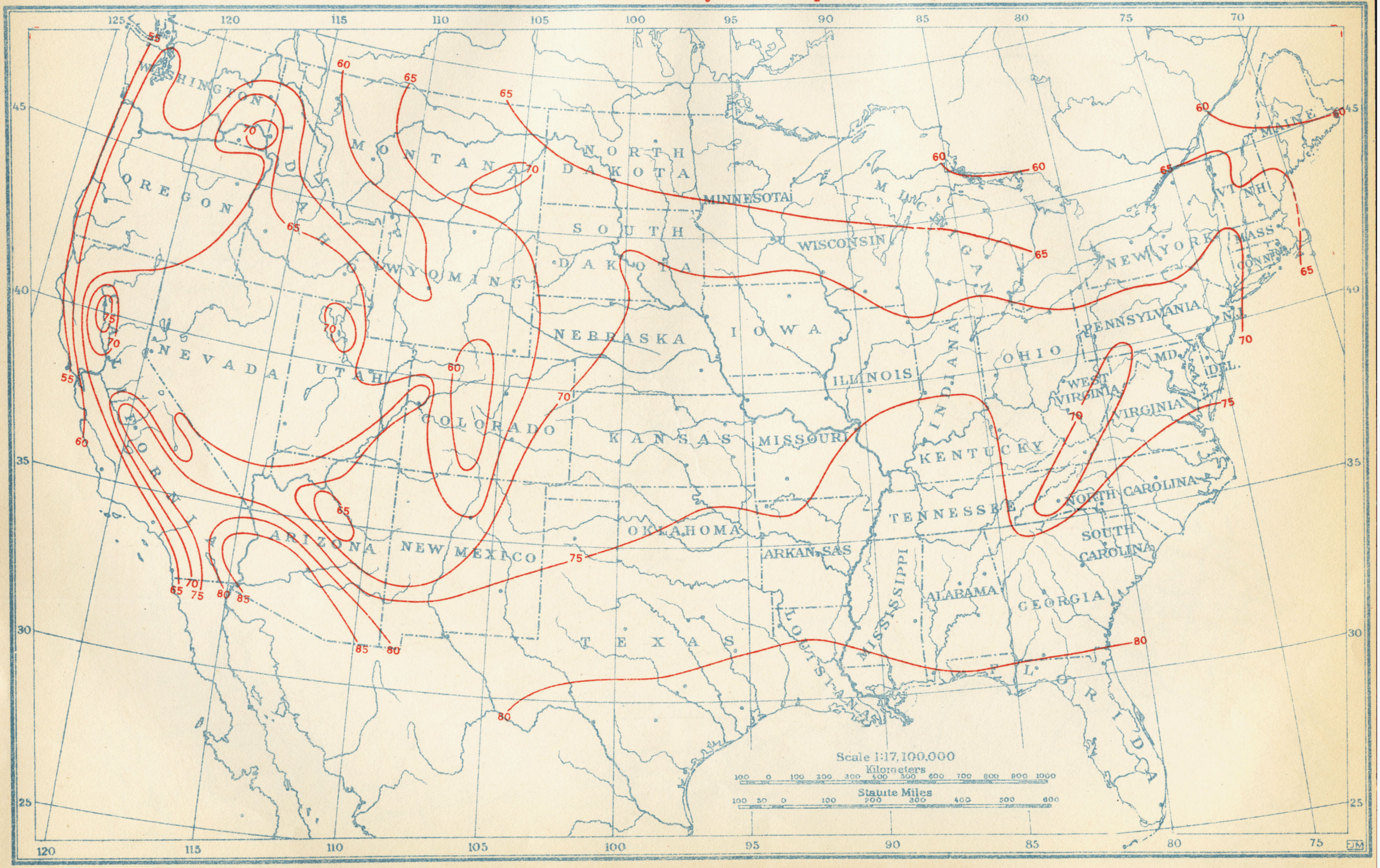
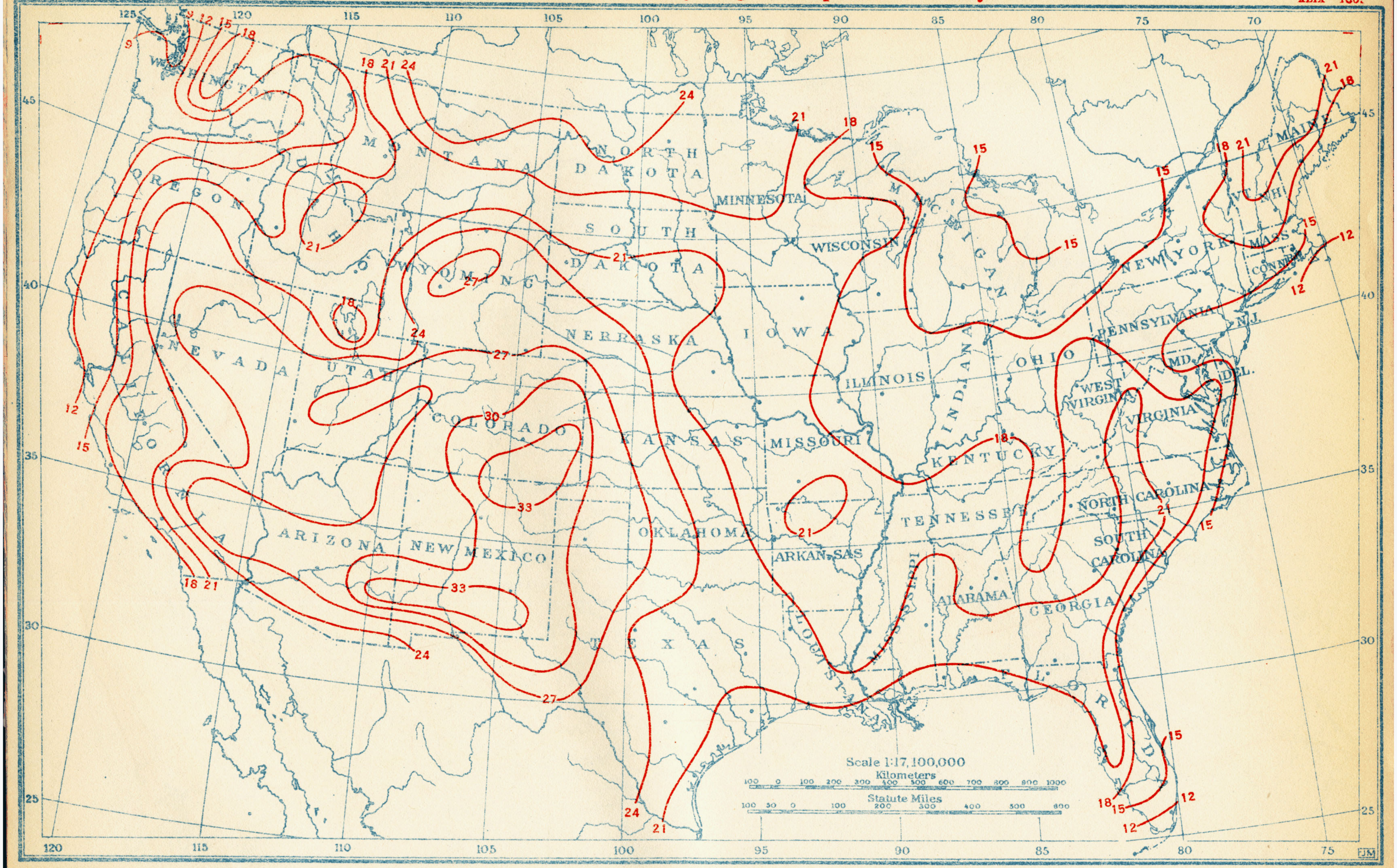
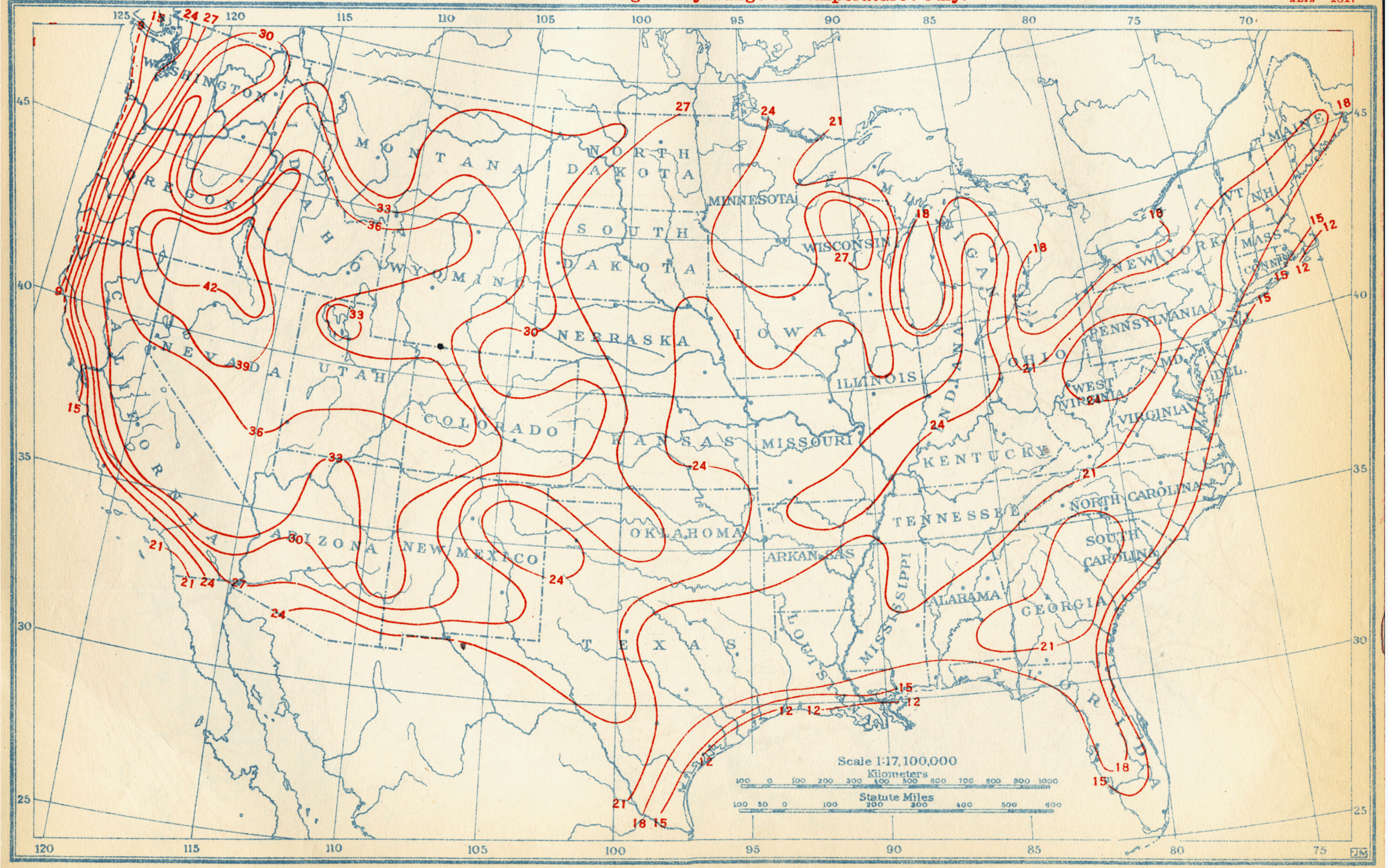
R. DEC. W. **XV.—Lowest Monthly Mean Temperature: July.**



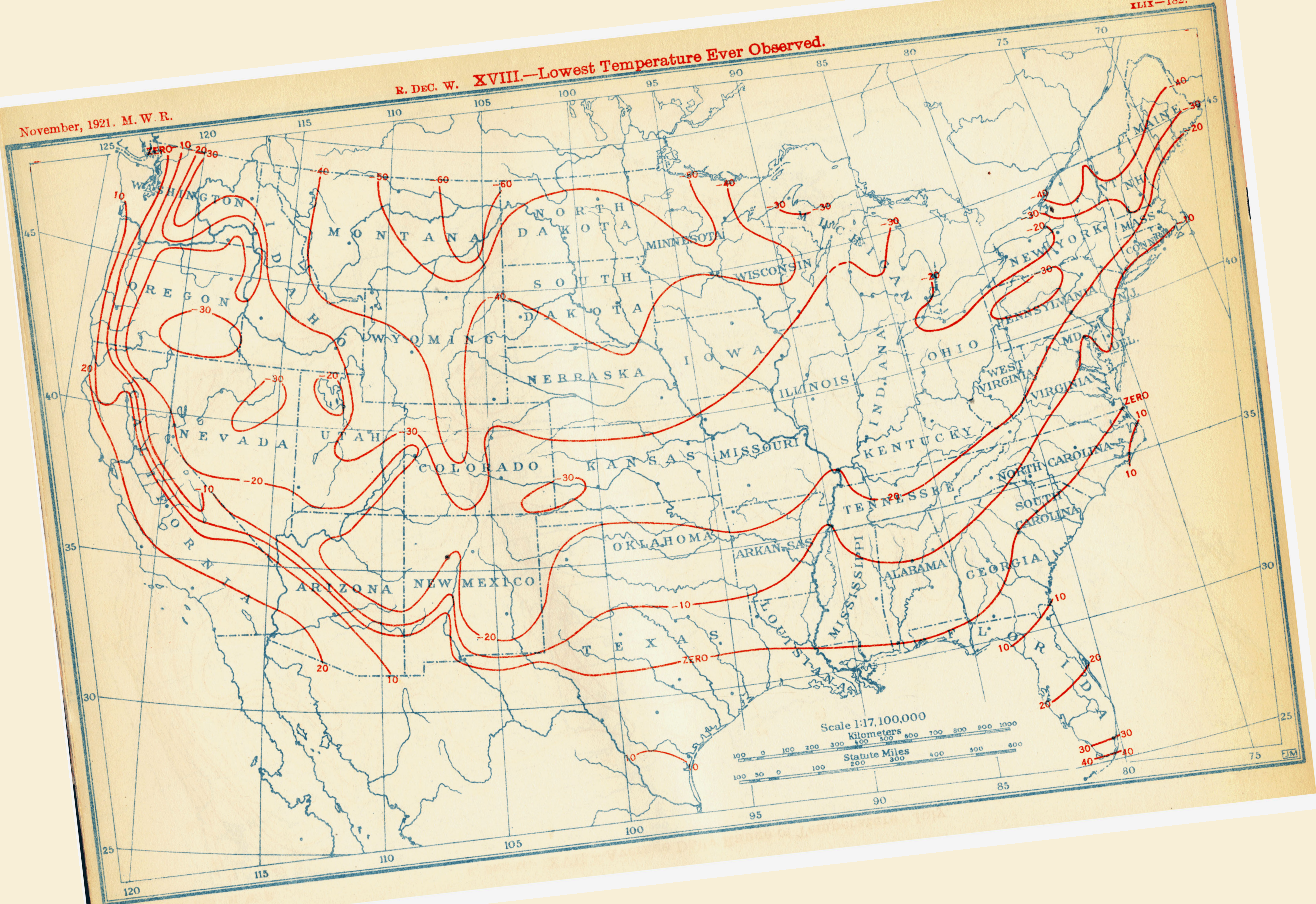
R. DEC. W. **XVI.—Average Daily Range of Temperature: January.**



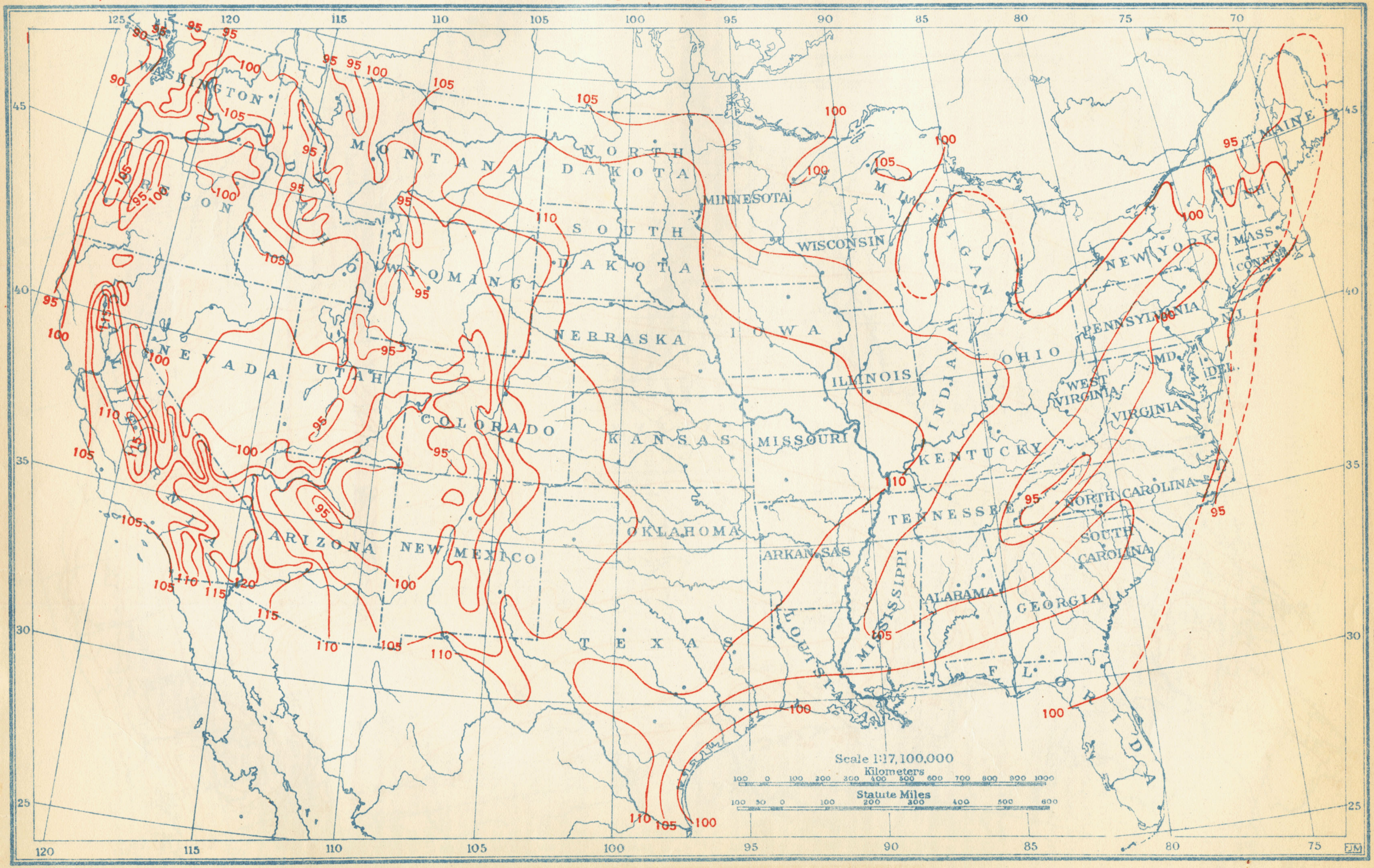
R. DEC. W. **XVII.—Average Daily Range of Temperature: July.**



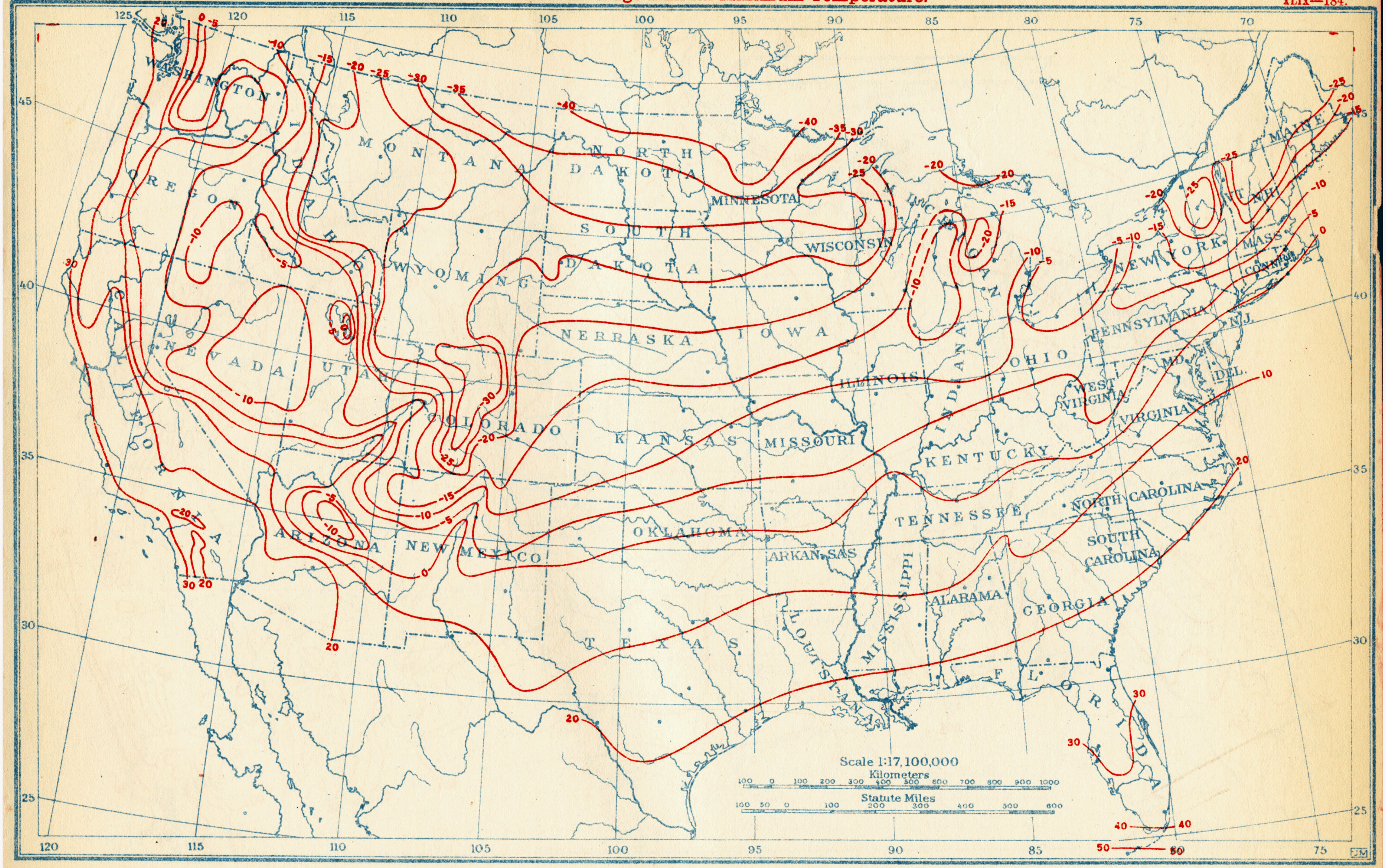
R. DEC. W. **XVIII.—Lowest Temperature Ever Observed.**



XIX.—Highest Temperature Ever Observed.



R. Dec. W. **XX.—Average Annual Minimum Temperature.**



new charts, which show *actual* temperatures and are constructed with due regard to topographic controls, are such a great advance over all earlier ones.

The greatest differences in temperature between different parts of the United States occur in winter, and it is then that the contrasts between land and water controls are most marked (chart 1). In midwinter (January), the extreme continental effect is seen in the occurrence of mean monthly temperatures of below 10° over the northern interior, between the Great Lakes and the Rocky Mountains, and in northernmost Maine. January means below zero are indicated on the northern border of North Dakota and Minnesota. The equatorward deflection of the isotherms over the northern interior region is a striking feature, which emphasizes, among other things, the fact that the western border of the Great Plains and the eastern foothills of the Rocky Mountains are warmer, in spite of their greater elevation, than the lower-lying country farther east. The general tendency of the eastern and southern isotherms to bend in uniformity with the Atlantic and Gulf coasts shows a tempering effect of the ocean and Gulf waters, which, however, is not very marked owing to the general prevalence of offshore winds. Along the northern shores of the Gulf of Mexico, temperatures of 50°–55° are found. Southern Texas and most of Florida have over 55°. Going south from Duluth to New Orleans, or from the coast of northern Maine to southernmost Florida, the January mean temperatures increase at the rate of about 2.5° for each latitude degree (70 miles). The popularity of southern winter resorts is thus easily explained. Health seekers and "warmth seekers" find the average monthly temperature in January increasing at the rate of about 1.5° for every hour of travel southward in a fast express train. There are two or three areas in the eastern United States where marked local irregularities in the isotherms exist. The northern portion of the Hudson–Lake Champlain depression is clearly indicated as a district of local cold. The central Appalachians show an equatorward warping of the isotherms, and the occurrence of low mean temperatures in certain valleys. A third, and more notable, local irregularity is seen in the Lake region. The moderating influence of the open waters is carried to leeward by the prevailing westerly winds, so that certain stations on the lee shores have somewhat higher winter means than do those on the opposite (windward) shores. The effect is clearly shown in the case of Lake Michigan, where the isotherms of 20° and 25° are bent poleward over the Lake and equatorward again over the lower peninsula of Michigan. The general spreading and warping of all the isotherms in the Lake region is another indication of the local effects due to the Lake waters. Several writers have called attention to this situation.[11] In one of the most recent of these studies, C. H. Eshleman has made a comparison of the temperatures at Grand Haven, Mich., on the eastern shore of Lake Michigan, with those at Milwaukee, Wis., on the opposite (western) shore, and has also compared Grand Haven with a group of inland stations in the same latitude, in Wisconsin, Iowa, and South Dakota. During the colder season, the mean monthly temperatures at Grand Haven run 2°–4° higher than those at Milwaukee, and 5°–8° higher than those at the group of western inland stations.

[11] See, e. g. Alexander Winchell: The Isothermals of the Lake Region. *Proc. Amer. Assoc. Adv. Sci.*, vol. 19, 1870, pp. 106–117; C. Abbe: The Influence of the Lakes on Temperature of the Land, Mo. WEATHER REV., 1900, 28, 343–345; W. F. Cooper: Air and Water Temperatures, ibid., 1905, 33, 521–524; C. H. Eshleman: Climatic Effect of the Great Lakes as Typified at Grand Haven, Mich., *Met'l. Chart of the Great Lakes*, U. S. Weather Bureau, Sept. 1913.

Lorin Blodget, in his now almost forgotten classic, emphasized several of the most striking characteristics of the winter temperature distribution in the United States.[12] He called attention to the occurrence of the lowest winter temperatures to the west of the Great Lakes, "the point of natural minimum" being "broken up by the Lakes" whose location is "most fortunate for the cultivable districts of this part of the United States." He noted the diminished warming effect of the Gulf of Mexico in winter, owing to the "great relative refrigeration of the continent, generally, and the consequent prevalence of land (i. e., offshore) winds," and called attention to similar conditions along the Atlantic coast where, "if the prevalent winds were reversed, the climate would be greatly softened."

In the East, in spite of various irregularities in the isothermal system, the major control over the temperature distribution is obviously latitude. The situation is wholly different over the western mountain and plateau area. Here the isotherms are warped, and crowded or spread apart as the topography may determine. Indeed, even broad generalization is unsatisfactory. A study of the map itself is the only way to gain a good view of the actual situation. It is true that latitude plays a considerable part in determining certain large facts. For example, while the southern deserts of Arizona and southeastern California have January mean temperatures over 50°, the northern plateau, in Washington, has about 20°. But the deserts are of low altitude, while parts of the Washington plateau attain elevations of 1,500–2,000 feet. Beyond these large facts, the temperatures of the mountain and plateau area can not be adequately generalized. Under control of altitude and local topography, supplemented to some extent by latitude, the January isotherms vary from 15° to 55°. Further discussion would lead well into the field of local climatology. It should be observed, however, that the temperatures average higher west of the Rocky Mountains than they do to the east, although the altitudes to the west are greater.

In the Pacific province a very striking feature is the parallelism of the westernmost isotherms with the coast. From north to south there is only a slight increase in temperature. The stations on the coast of southern California, for example, are only a very few degrees warmer than San Francisco, and the extreme northern coast of Washington (40°+) is less than 15° cooler than the extreme southern coast of California (50°+). Latitude is obviously here a very subordinate control, especially when the Pacific coast is compared with the Atlantic. The rate of change of temperature along the entire length of this coast is only about 0.8° per latitude degree, which is less than one-third of the temperature gradient along the Atlantic coast in the same month. Clearly, the prevalence of onshore winds from a relatively warm ocean explains the moderate and noticeably uniform winter temperatures along this coast. Inland, various topographic features are distinctly indicated in the isothermal system. The California Valley, the lower portions of which are inclosed by the 45° isotherm, is contrasted with the lower temperatures of the Sierra Nevada. In southern California, the interior highlands are distinctly cooler than the seacoast. The Valley of Oregon is outlined by its own inclosing isotherms, as is the Columbia River Valley, where the isotherms indicate almost as well as contour lines the gap through the mountains. In Washington, the Olympics and the Cascades are notable features, with

[12] Lorin Blodget: "Climatology of the United States," etc. Philadelphia, 1857.

their lower temperatures as compared with those of the neighboring lower lands. A comparison between the mean January temperatures on the Pacific and on the Atlantic coasts is interesting. The coast of southern California has essentially the same temperatures as have the corresponding latitudes on the southern Atlantic coast. San Francisco is 10°–15° warmer than the corresponding Atlantic coast. The coast of northern Oregon is 20° warmer than the same latitude on the coast of Maine. The excess in favor of the Pacific coast thus increases to the north.

The economic consequences of such winter temperatures as are experienced in the United States are many and varied. Over the cold northern and eastern sections agricultural operations must largely or wholly cease, and there is a general abandonment of outdoor labor except in the case of certain occupations, such as lumbering and ice cutting, which are best, or exclusively, carried on in winter. Transportation conditions are to a considerable extent readjusted. There is difficulty with severe cold and deep snows. The heavy summer vacation travel to the north and east ceases, but is replaced, to an increasing degree, by winter travel to the genial south. The close of navigation on the Great Lakes turns the transportation of freight to the railroads, or leads to a delay in shipments till spring. Many industries show seasonal controls, such as the manufacture of heavy winter clothing, of overshoes, and of rubbers. There is need of heating cars used for the transportation of food which is injured by cold. Even in the case of the shipment of iron ore, for example, as the ore freezes at temperatures somewhat below 32°, precautions must be taken not to have it exposed long at low temperatures. Over the districts of moderate or warm winters, on the other hand, as in the case of the Southern and Pacific Coast States, for example, outdoor and farming operations may continue all winter. The cooler months may, and usually do, bring a change in the character of the outdoor work, but not in its essential nature.

Very different are the conditions in midsummer (chart 2.) The distribution of temperature is far more uniform in July than in January. Between the northern tier of States (east of the Rocky Mountains), with mean temperatures of within a few degrees of 70°, and the southern tier and the Gulf States, with temperatures within a few degrees of 80°, the difference is so small that it attracts attention. On the other hand, the temperature differences between north and south in January are striking because they are so large. In July, the rate of change of temperature between New Orleans and Duluth is, in round numbers, only about 1° F. per latitude degree, while on the Atlantic coast, between Key West, Fla., and Eastport, Me., it is about 0.8°. So far as the mean temperatures alone are concerned, therefore, a long journey from south to north in search of decidedly cooler summers gives far less change than the corresponding trip from north to south in winter in search of much warmer and balmier climates. Other factors, however, serve to give the northern summer resorts their popularity. Among these are the frequent spells of cool weather; the advantages of cool fresh or salt water bathing; the lower temperatures, due to elevation, found in the mountains of New England and New York; and other conditions. The July isotherms show quite clearly the cooling effects of the Appalachian Highland in the warping of the lines and in the occurrence of temperatures averaging 5°, or even 10°, below those of the surrounding lowlands.

The tempering effects of even relatively moderate altitudes are shown in an interesting way by the course of some of the isotherms which are prominent features of the July map in the eastern United States. Take the case of the 70°-isotherm, for example. This line follows along the eastern base of the Rocky Mountain system from southern New Mexico northward to northeastern Wyoming, and then makes an abrupt turn eastward across the northern tier of States. Stations at no very great elevations in southern New Mexico are thus seen to have the same mean July temperatures as a long line of places reaching across northern South Dakota, central Minnesota, Wisconsin and Michigan, much of New York, and also southern New England. The situation is somewhat similar, but less marked, in the case of the 75°-isotherm. The tempering effects of the Great Lakes may be seen in the warping of the isotherms. Grand Haven, Mich., has mean temperatures 1° cooler than those of Milwaukee, Wis., in July and August, and 3°–4° cooler, between April and August, than those of a group of inland stations on the same latitude west of Lake Michigan.[13] Michigan stations on the immediate Lake shore are naturally also cooler than those situated somewhat inland, but this cooling influence on the mean monthly temperatures extends only to a distance of 20 or 25 miles inland, according to Henry.[14] Near the Atlantic coast the isotherms "double on themselves abruptly," as Blodget put it, indicating cooling "due either to the southward flowing cold surface currents or to the upwelling of cold water."[15] The northern coast of Maine has notably cool summers, cooler than those of the eastern coast of Asia in the same latitude.

Over the western Plateau province, the isothermal map is essentially a rough contour map. July mean temperatures below 55° are shown in certain portions of the Rocky Mountains in Montana, Wyoming, Colorado, Utah, and northern New Mexico; also on the Cascades of Washington and Oregon and the Sierra Nevada of California. Much of the Plateau province has from 65° to 75°. The highest monthly mean (over 90°) occurs over a restricted area of southwestern Arizona and southeastern California. This "heat island" is much smaller and less conspicuous than it appears on earlier charts, as, e. g., on the *Challenger* July (sea-level) isothermal chart, where the 90°-isotherm incloses a considerable part of the Southern Plateau region. The close crowding of the isotherms on the mountain and plateau slopes; the distinctly lower temperatures at the greater elevations, and the contrast between the excessively heated southern deserts and the much cooler, more elevated, stations not far away, are the most striking features in this western interior district. The effects of altitude are here so considerable that latitude and land and water controls are of relatively subordinate importance. Hence the popularity, at least in part, as summer vacation resorts, of the mountains of Colorado; of Yellowstone National Park, and of other parts of the Rocky Mountain district.

On the Pacific slope (Pacific province) there are three very striking features on the map. (1) The seaward isotherms closely parallel the coast line, giving, as Blodget remarked, "almost absolutely equal temperatures" along this coast.[16] One may travel from the Strait

[13] C. H. Eshleman, *loc. cit.*

[14] See also H. J. Cox and J. H. Armington, The Weather and Climate of Chicago. Large 8vo. Chicago, Ill., 1914, pp. 37–46, 142–145, on the influence of Lake Michigan on temperatures at Chicago.

[15] *Atlas of Meteorology*, p. 12.

[16] *loc. cit.*

of Juan de Fuca as far south as San Francisco without any change in the mean monthly temperature, and continue the trip to the southermost part of the coast without reaching a mean temperature as high as 70°. The temperature gradient along the entire length of the Pacific coast, from San Diego to the Strait of Juan de Fuca, is only 0.7° per latitude degree, i. e., one may travel north nearly 1,200 miles without changing the mean temperature more than about 12°, or 1° to 100 miles. (2) A second notable feature is the extraordinarily rapid temperature gradient between the immediate seacoast of southern California, with its cool summers resulting from the prevailing onshore winds, and the greatly heated interior desert of southeastern California. The west-east gradient from the coast to the southern portion of the San Joaquin Valley is also very rapid. This phenomenon "of the juxtaposition of Scottish and mid-African summer conditions" is almost, if not quite unique.[17] The superheating of these interior districts is due to their low latitude, abundant sunshine, dry air, and effective inclosure from the sea. (3) The third feature is the marked contrast between the higher temperatures of the interior valleys and the cooler mountain slopes. This is especially well seen in California, where the Sacramento-San Joaquin Valley stands out clearly by reason of its fairly uniform high temperatures. The increasing resort to the Sierra Nevada during the summer months finds a simple explanation in these conditions of temperature. This topographic control is naturally less marked farther north. The summers on the Pacific coast are as a whole several degrees cooler than those on the Atlantic.

Average winter and summer temperatures.—The average temperature of the three winter months is shown in chart 3, which summarizes, in a convenient form, the temperature conditions of this season. Owing to difficulties in reproduction, it is necessary, unfortunately, to omit the chart showing the average temperature of the three summer months. However, reference to chart 2 will reveal the essential characteristics of the summer season.

Mean annual ranges of temperature.—The seasonal contrasts in temperature are conveniently summarized by means of the so-called mean annual ranges, which shows the difference between the mean temperatures of the warmest and coldest months.[18]

Previous charts were based on sea-level, not on actual, temperatures. The new isothermal charts for January and July have now made it possible, by a comparison of the lines of actual temperatures for these two months, to study for the first time in great detail the ranges in all parts of the United States.

The greatest differences between the mean temperatures of January and of July are found over the northern interior region between the Rocky Mountains and the upper Lakes, viz, 55°–60°, and even slightly over 60° in some cases. From this center, the ranges decrease in all directions.

It is to be observed, however, that the continental characteristics of warm summers and cold winters prevail even to the extreme limits of the land area to the east. The absence of any effective mountain barrier to the west, somewhat inland from the coast, and the prevalence of offshore winds, explain this condition. Thus, ranges of 40°–50° are found even along the central and northern portions of the coast. The modifying effects of latitude and of the Gulf of Mexico are seen in the somewhat smaller ranges which prevail in the Gulf Province (25°–30°, or less). Most of the rest of the eastern province has 40°–50°. Over the southern Plains and much of the Plateau province the ranges run from slightly above to somewhat below 40°.

The annual migrations of the isotherms and of the temperature belts.—Too much emphasis upon the conditions in January and in July gives a misleading impression of the actual march of temperature through the year. It is important to have clearly in mind the fact of the continual advance or retreat of the isotherms, not only month by month, but week by week, and even day by day. The isothermal chart of any one month is merely a "snapshot" of conditions which are in a constant state of flux. It represents no rigid, fixed, permanent situation. It is, therefore, instructive to view the isothermal charts of the 12 months together. (Charts 1, 2, 4–13.)

January and July are the extreme types. They simply show the limits reached during the seasonal migration poleward and equatorward. Each of the other maps is almost as important, in that it marks another stage of advance or retreat. With the northward advance of the sun, the succeeding months of late winter, spring and early summer show the gradual rise in the temperatures everywhere, the changes being greatest over the northern and interior districts which have the greatest mean annual ranges. The seasonal northward advance of the isotherms is naturally most readily seen over the eastern United States, where the lines of equal temperature are well separated and follow more or less along the latitude circles. Even a cursory glance at the charts for January to June shows the northward movement of isotherms which are over the Gulf States in midwinter and travel northward so far that they leave the United States altogether, moving across the International Boundary into Canada. The gradual spreading apart of the eastern isotherms as the season advances is also very obvious. In January, 12 isotherms are shown between the northern Plains and the Gulf of Mexico. In July, when the continent is well and very uniformly warmed, there are only three. Over the Plateau districts, the general system of the isotherms remains more or less the same, month by month, but the lines are on the whole somewhat more crowded during the warmer months in certain areas, indicating greater differences of temperature between lowlands and uplands in summer than in winter in those localities. The seasonal increase in all the temperatures is readily seen if the figures on the chart are studied. On the immediate Pacific coast the parallelism of isotherms and coastline remains a constant feature on all the maps, and the seasonal changes in the actual temperatures are, as already pointed out, relatively slight.

During the cooling months (August–January) the isothermal system travels equatorward. Lines which in summer extended well north over the United States now travel so far south that they disappear from the map, e. g., the 70°- and the 75°- isotherms. In their place isotherms which in July were far north in the Arctic regions, or which did not even appear at sea level at all, gradually move equatorward and one after another appear on the charts. Over the western mountains and plateaus, and to a less marked degree over the eastern Appalachians, the advance of the colder season means the gradual descent down the slopes, to lower and lower levels, of isotherms which during the colder months were

[17] *Atlas of Meteorology*, p. 12.

[18] The standard chart of mean annual ranges for the world, based on the *Challenger* sea-level isotherms for January and July, is that of J. L. S. Connolly: A New Chart of Equal Annual Ranges of Temperature, *Amer. Met. Journ.*, vol. 10, 1893–94, pp. 505–506. This chart is reproduced in *Atlas of Meteorology*, pl. 2; text, p. 8; in W. M. Davis: Elementary Meteorology, fig. 18, and elsewhere. No more recent chart is available for the United States.

either far up on the upper slopes or even in the free air far above the tops of the highest mountains. Thus the sun is forever impelling advances and retreats, ascents and descents of all isotherms on all maps. There is no such thing as a fixed condition of temperature distribution. When this conception is thoroughly in mind, isothermal maps have a new meaning. They are no longer dead and rigid, but are full of movement, suggesting an infinite number of relations between the everchanging temperatures and all of human life and activity.

January and July have been referred to as everywhere the coldest and warmest months. This is true for the vast majority of stations, and in the long run. There are, however, a few stations exposed to marine influences on the Pacific coast, or on the Great Lakes, which have retarded maxima or minima. February may then become the coldest month or August the warmest. San Francisco is unique in having its warmest month September, and its October is actually warmer than its July and its August. This peculiar conditions results from the prevalence of strong onshore winds blowing through the Golden Gate in summer and induced by the excessive heating of the interior valley. The hotter the valley the more marked are these inflowing cool winds from the Pacific Ocean.

The advent of spring.—The so-called "advent of spring" may be said to occur when the physiological life of trees and plants awakens, after the quiescent stage of the colder months. The temperature of 42.8° F. (6° C.) being about that at which the life of the plant cells begins to stir, a chart showing the position of the isotherm of 43.8° (1° above 42.8°) at the beginning of February, March, April, and May may be taken as indicating the dates of the advent of spring in different sections of the country. Such a chart, proposed 30 years ago by Harrington, shows that spring really comes from the southward and westward, i. e., it advances northward and eastward.[19] The progress is not a steady one, but occurs as a series of advancing and retreating fluctuations, associated with the occurrence of warm and cold waves, "each advance of warmer weather penetrating a little farther into the cold interior and each successive chilling halting a little north of the southern limit of its predecessor, until finally * * * summer conditions are firmly established."[20] It has been pointed out by Henry that the statement concerning the advance of spring from south and west is really strictly applicable only to the northern portions of the Missouri, Mississippi, and Ohio Valleys.[21] On the Pacific coast plant activity, to a greater or less degree, continues through the colder months, and over the rough and broken topography of the Rocky Mountain and Plateau districts frequent local spring frosts, following warm days, interfere with the orderly advance of spring.

The temperature gradients and their economic significance.—With the warm Gulf of Mexico in the south, and cold continent to the north, the January isotherms over the eastern United States must necessarily be closely crowded, as already pointed out. The rapid January poleward temperature gradient on the Atlantic coast from southern Florida to northern Maine (about 2.5° per latitude degree), already referred to, remains essentially the same if Labrador be taken as the north end of the scale instead of Maine. Considering the distance, this is the steepest temperature gradient in the world. Where such rapid temperature gradients occur elsewhere, they are limited to much shorter distances, as, e. g., in the case of the opposite sides of mountain ranges. It is a noteworthy fact that in the United States there are no transverse mountains to help in the production of this remarkable contrast between north and south. Woeikof first called attention to the economic importance of this steep temperature gradient.[22] The products of tropical and of polar lands are here separated by less distance than is the case anywhere else in the world. At the same time, communication between these districts of sharply contrasted climates and types of vegetation is easy. Labrador is an Arctic land, where man's food must be sought chiefly in the ocean. Florida, on the other hand, is in many respects tropical. This idea has been somewhat expanded by Miss E. C. Semple.[23] "This approximation of contrasted climatic districts in North America was an immense force in stimulating the early economic development of the Thirteen Colonies, and in maturing them to the point of political autonomy. It gave New England commerce command of a near-by tropical trade in the West Indies, of subtropical products in the southern colonies in close proximity to all the contrasted products of a cold climate—dense forests for naval stores and lumber, and an inexhaustible supply of fish from polar currents, which met a strong demand in Europe and in the Antilles. The sudden southward drop of the 0° C. annual isothermal line toward the St. Lawrence and the Great Lakes brought the northwestern fur trade to the back gate of New York, where it opened on the Mohawk and upper Hudson, and brought prosperity to the young colony."

A steep poleward temperature gradient is a perfectly normal condition on the east coast of continents in middle latitudes, as a result of the prevailing winds and the system of ocean currents. Nevertheless it is significant that the January poleward gradient in eastern North America is nearly twice as great as that in eastern Asia (about 1.5°). The explanation was given by Woeikof. North America has a warm body of water—the Gulf of Mexico—on the south. There is also an increasing prevalence of warm (SW.) winds toward the southern portion of the Atlantic coast district, while cold northwesterly winds distinctly predominate in the north. In eastern Asia, on the other hand, cold offshore winds prevail as far south as the Tropic, and a cold land occupies the position of the Gulf of Mexico. North of latitude 50° N., the mean annual temperatures in eastern Asia and eastern North America are more or less alike. Farther south, eastern Asia becomes distinctly colder, especially in winter. As Hann put it, "comparing eastern Asia with eastern North America, the latter is not too cold in the north but too warm in the south. It is to this fact that the more rapid change of temperature with latitude in North America is due. The winters on the east coast of Asia are more severe than those on the American coast. Even the interior of America is much warmer than the east coast of Asia in corresponding latitudes."[24] A comparison between eastern North America and the west coasts of Europe and of northern Africa was apparently first clearly made by Humboldt, who pointed out that the mean annual temperatures found in the higher latitudes (55°–70° N.) on the European side of the Atlantic occur 10°–12° of latitude farther south in North America. In middle latitudes (about 45° N.), this difference decreases to about 4°–5° of latitude. At latitude 30° N. the difference between the two sides of the Atlantic disappears.

[19] M. W. Harrington: The Advent of Spring. *Harper's Mag.*, May, 1894, pp. 874–879.
[20] A. J. Henry: Climatology of the United States, p. 21.
[21] *Loc. cit.*

[22] A. Woeikof: Die Klimate der Erde, 1887, pp. 43–44.
[23] Ellen C. Semple: Influences of Geographical Environment, 1911, p. 618.
[24] J. Hann: Handbuch der Klimatologie, 3d ed., vol. 3, pp. 354–356.

The January poleward temperature gradient on the west coast of Europe is slightly less than 1° F. per latitude degree, as against more than 2.5° F. in eastern North America. The January gradient along the whole Pacific coast of North America as far as Sitka, Alaska, is essentially like that of Europe, and is thus only slightly over one-third of that along the whole Atlantic coast. The July gradients on the west coast of Europe (0.65°) and the east coast of Asia (1°) may be compared with those on the Atlantic coast of North America (about 1°) and the Pacific coast of North America (about 0.7°).

The occurrence of months and of seasons warmer or colder than normal.—It is a widespread popular belief that individual months, in different years, are often much warmer or colder than the normal for those months. The expression is a familiar one, "this February was the coldest I ever experienced," or "September was the hottest I remember." This belief is usually based, not on the fact that the mean temperature of the month in question may have been a degree or so higher or lower than the normal for that month, but rather on the values of the highest and lowest temperatures, and on the way in which these were distributed, i. e., on the "spells" of heat or cold, and on their severity. In fact, it frequently happens that people think that a month was colder than normal when its mean temperature was actually somewhat above the normal, and vice versa. In other words, the departure of the mean monthly temperature from the normal can not, in most cases, be estimated by the general impression of heat or cold which the month made.

It is a fact that the mean temperature of the same month in different years does depart a considerable amount, over much of the United States, from the general mean temperature of that month as derived from the whole series of observations. Almost any random publication which includes the monthly mean temperatures for a series of years, or which gives, for any single year, the departures of the mean monthly temperatures in that year from the normal, will furnish illustrations of this point. It is, for example, no uncommon thing in any individual year to have December or February colder than January, although in the run of the years January is the coldest month. When the average of the departures from this general mean are determined (regardless of whether they are + or −), the *mean departures of the monthly means* from their average values are obtained.[25] The calculation of such data is laborious, and has not been carried out to any considerable extent. The available results are, however, sufficient to warrant broad generalizations. Supan and Hann determined mean departures of the monthly means for certain parts of North America.[26] Henry has given the most recent tabulation, for a few stations only, from which it appears that the January departures are of the order of 6°–7° on the northern Plains. From this region of maximum average departures there is a decrease to the west, south, and east. The departures for January on the Pacific coast are of the order of 2° to about 2.5°; over the southern Plateau, the Southern Plains, and the Gulf States, about 3°; 3°–4° in the Lake region, New England, and the central tier of States east of the Rocky Mountains generally. In July, all these departures are reduced to one-half, or less than one-half.[27] The mean temperatures of winter months in the interior of North America are as a whole subject to greater fluctuations than is the case in northern Germany, and almost twice as great as those in England.

While such variations in the mean temperatures of the individual months in different years are significant, they are of slight physiological interest. (1) These differences come a year apart. (2) The monthly means, as has been stated above, are usually not values which can be determined by one's sensations. (3) Furthermore, within a year, many other fluctuations of temperature occur, much closer together and of much greater amount, which are directly observable and have many direct physiological and economic effects.

Extreme limits of the mean temperatures of individual months.—People are also naturally interested in knowing what mean temperature the coldest January, or the warmest February, etc., on record, actually had. When such data are available, a chart may be drawn showing just what difference there has been, within the period of record, between the mean temperatures of any given month. Such charts have been constructed by Henry, and published in 1906.[28] They show what is known as the absolute range of the monthly mean temperatures. Over a large portion of the central United States, including nearly all of the Missouri and the middle and upper Mississippi valleys, the mean monthly temperatures of January have differed by 25° and more. To illustrate, a station whose January mean temperature is 10° may have had one January with a mean of 25°, and one with a mean of 0° or even slightly below. Such departures, having occurred during a relatively short period of observation, are of course likely to occur again, and even to be exceeded. From the interior district of the largest ranges there is a decrease in all directions. Over the Atlantic and Gulf coasts the oscillation of the monthly means is roughly 15°–20°. On the Pacific coast and in the southwestern interior it is smaller (8°–16°). In July, the amount of such oscillations is about one-half of those of January. The California coast has essentially the same conditions in the two months.

In connection with this same subject, charts 14 and 15 are interesting. They show the lowest monthly mean temperatures recorded in January and in July during the period 1895–1914, as shown by the records of about 200 regular Weather Bureau stations. Chart 14 should be compared with chart 1, and chart 15 with chart 2. It will be observed that the *lowest* January mean temperatures have run about 5°–10° below the *average* mean temperatures, the departures being smallest on the Pacific coast and in Florida. In July, as is to be expected, the departures are smaller, being about 5°, or less.

Traditions regarding unusual seasons.—As far back as tradition and the non-instrumental record of white men in the United States extend, there are references to the occurrences of "unusually" severe or mild winters, and of "unusually" hot or cool summers. There were winters in northern sections when there was little ice; when flowers blossomed outdoors; when the ground was hardly frozen. There were also winters when the intense cold lasted almost without interruption; when snows were deep; when outdoor occupations and transportation were greatly interrupted. In the Records of the Roxbury (Mass.) Church, kept by Rev. John Eliot, the Apostle to the Indians, the winter of 1646–47 is described as having brought "no snow all winter long, nor sharp weather," so that it was possible to "go

[25] Also known as the variability of the monthly mean temperatures.

[26] J. Hann: Handbuch der Klimatologie, 3d ed., Vol. I, p. 26; Lehrbuch der Meteorologie, 3d ed., p. 110; A. Supan: Grundzüge der Physischen Erdkunde, 3d ed., 1903, pp. 101–102.

[27] A. J. Henry: The Climatology of the United States, *Bulletin Q*, U. S. Weather Bureau, pp. 31–32.

[28] Loc. cit., Charts XVII, XVIII.

preach to the Indians all this winter, praised be the Lord." Similarly, there are accounts of "unusually" hot, and of unusually cool summers. The summer of 1816 was a "record-breaking" one. Chauncey Jerome, who was then living in Bristol, Conn., wrote: "I well remember on the seventh of June, while on my way to work, about a mile from home, dressed throughout with thick woolen clothes and overcoat on, my hands got so cold that I was obliged to lay down my tools and put on a pair of mittens which I had in my pocket. It snowed about an hour that day." And again: "On the fourth of July I saw several men pitching quoits in the middle of the day with their overcoats on."[29]

Recent studies of exceptional seasons.—It is, however, only very recently that any detailed studies of the actual temperature conditions of such abnormal seasons have been made. To take a recent example, the winter of 1917–18 was remarkably cold, with heavy snowfalls, over an enormous area east of the Rocky Mountains. The autumn months were in many cases the coldest on record. December and January "defied the memories of the oldest inhabitants;" new minimum temperatures were registered far and wide. Heavy snows, with intense cold, brought serious economic and transportation disturbances over northeastern districts. Even in the South, truck gardens and fruit crops were seriously damaged. On January 12, 1918, a blizzard, with snow driven by a gale and at a temperature as low as —20°, resulted in an almost complete interruption of traffic during two days.[30]

The winter of 1920–21, on the other hand, was one of unusual and persistent mildness east of the Rocky Mountains. Kincer has given a graphic description of the "involuntary climatic travels" made by the inhabitants of different portions of the eastern United States. The high temperatures were the equivalent of travel over considerable distances to the south.[31] "The people in central North Dakota, climatically speaking, spent the winter near the South Dakota-Nebraska boundary line; those at Sioux City, Iowa, at Kansas City, Mo.; southern Indiana in northern Tennessee, and Washington, D. C., in southern Virginia." In 1919–20, a colder winter than usual, "Richmond (Va.) came north, climatically, to Washington to spend that winter, and went south to Raleigh, N. C.," in 1920–21.

It has not yet been possible to work out in detail the actual causes of these marked monthly and seasonal variations in temperature in different years. The explanation, in the United States as elsewhere, undoubtedly lies in the general distribution of pressure over the continents and oceans, i. e., in the development and location of the centers of action, and in the resulting effects upon the numbers, intensity, and paths of cyclones and anticyclones. It is as yet too early to say in just what ways the variations in the intensity of solar radiation may act to bring about these results.[32]

Do temperatures show any permanent change?—While monthly and seasonal mean temperatures are, as has been seen, subject to wide fluctuations, there is no unimpeachable evidence that any *permanent change* in temperature is taking place, or has taken place within historic times, in the United States. Periodicities, of varying lengths of years, have been suggested by numerous writers. The results differ widely. There is no general agreement except in the case of the Brückner 35-year period. The amount of temperature-difference, where such has been reported, is relatively very slight, and furnishes no basis, as yet, for making any reliable scientific long-range forecasts of general economic value. A discussion of these investigations can not be entered into here. The first thorough study of this subject was made by Schott, in his monumental analysis of the temperatures of the United States, in which he collected, reduced, and discussed all the older records.[33] Nothing was found which led to the view of any progressive change, although there was evidence of similar fluctuations of temperature over considerable areas, e. g., a period of about 22 years on the Atlantic coast and one of about 7 years in the interior. The long record of the opening and closing to navigation of the Hudson River at Albany, N. Y., indicates no progressive change in these dates.

Some 20 years ago, W. B. Stockman compiled temperature data for 10 stations, mostly east of the Mississippi River, covering 50 years.[34] The conclusion was that "the contention that the winters of recent years are less rigorous than those of former years, at least so far as temperature is concerned, is not well founded."

In a recent study of temperature variations in the United States, Henry has investigated the question to what extent periods of abnormally high and low temperatures synchronize, and also whether or not there is evidence of a periodicity in the occurrence and recurrence of these phenomena.[35] The data covered the period 1888–1919. It appears that in the United States the range in temperature from the year of highest temperature at sunspot minimum (1900) to the year of lowest temperature in a year of sunspot maximum (1917) amounts to 2.5° F. "The bulk of the evidence points to a period of between three and four years, or a third of the sunspot cycle, as being (the length of the period of oscillation) most commonly experienced."

In several cases a study of the records has shown that there is often, for a time, a certain sequence in the occurrence of especially cold, or warm, or rainy, or dry seasons. Facts of this sort have here and there been made use of in making very generalized long-range forecasts. Brooks has recently discussed the sequence of mild and severe winters in the northeastern United States.[36] An examination of the mean winter temperatures since 1812 shows apparently no other than a chance relationship four-fifths of the time. The other fifth includes two notable series of "alternating cold and warm winters, with almost identical preliminaries of a few moderately mild winters, an ordinary or moderately cold winter, and then a severe winter, which opens the alternating series —severe, warm, severe, warm, etc. The opening severe winters in these two series were those of 1872–73 and 1917–18. Thus we examine with interest the records of the winters of 1876–77, 1877–78 * * *, 1882–83, and

[29] History of Clock-Making. Numerous accounts of unusual seasons in New England will be found in Sidney Perley: Historic Storms of New England, Salem, Mass., 1891.

[30] An interesting account of this remarkable winter has been written by Dr. Charles F. Brooks: The Old-Fashioned Winter of 1917–18, *Geogr. Rev.*, vol. 5, 1918, pp. 405–414. See also P. C. Day: The Cold Winter of 1917–18, MO. WEATHER. REV., vol. 46, 1918, pp. 570–580.

[31] Joseph B. Kincer: Our Involuntary Climatic Travels (with Special Reference to the Warm Winter of 1920–1921), MO. WEATHER REV., 1921, 49: 18–20. Chart.

[32] See, in this connection, E. H. Bowie: Long Range Weather Forecasts, in *Weather Forecasting in the United States*, U. S. Weather Bureau, 8 vo., Washington, D. C., 1916, pp. 341–348; C. F. Brooks: World-Wide Changes of Temperature, *Geogr. Rev.*, vol. 2, 1916, pp. 249–255; W. J. Humphreys: Physics of the Air, 8 vo., Philadelphia, 1920, pp. 614–625; J. Hann: Lehrbuch der Meteorologie, 3d ed., 1915, pp. 637–644; E. A. Beals: Meteorological Centers of Action in the North Pacific Ocean (Abstract), MO. WEATHER REV., 1921, 49; 330–331.

[33] Charles A. Schott: Tables, Distribution and Variations of the Atmospheric Temperature in the United States and some Adjacent Parts of America. *Smithson. Contr. to Knowl.*, XXI, 1876, pp. 302–320.

[34] Wm. B. Stockman; Invariability of our Winter Climate, MO. WEATHER REV., 1904, 32; 224–226.

[35] Alfred J. Henry: Temperature Variations in the United States and Elsewhere, MO. WEATHER REV., 1921, 49; 62–70.

[36] Charles F. Brooks: Sequence of Winters in the Northeastern United States, MO. WEATHER REV., 1921, 49; 71–73.

wonder whether the winters of 1921–22, 1922–23 * * *, 1927–28, will alternate cold, warm, cold, etc., as those of 45 years ago did for such a long period * * *. Even if we can not say for winter after winter what the character is likely to be, we can say that immediately after a cold winter the chances are two to one or better in favor of a mild or warm one, and that a period of alternating cold and warm winters which is general over a large part of the eastern United States may continue for several winters, as cold, warm, cold, etc."

Temperature changes during 24-hour intervals.—There are two fundamental types of temperature changes during the conventional 24-hour time unit. One is the normal change, on fine days with marked solar control, from just before sunrise to shortly after noon—from a cool night to a warm afternoon. The other is the irregular change, not related to the time of day, due to winds, clouds, etc., and resulting from cyclonic or anticyclonic controls. There are, obviously, all varieties of combinations of these two types. The first, i. e., the so-called normal diurnal type, is chiefly characteristic of the semiarid western plateau district, where a prevailing small amount of cloud, dry air, and sparse vegetation favor strong sunshine by day and active radiation at night, but is also a common feature elsewhere, especially during the warmer months and in the Southern States. The second, i. e., the irregular cyclonic type, is mainly characteristic of northern and eastern sections. It is also relatively frequent during the colder months everywhere, being least marked on the southern Pacific coast and in the South and Southwest. This type is best developed when the cyclonic control is strongest, in winter, but occurs with reasonable frequency, although with greatly diminished intensity, in connection with the weaker cyclonic control of summer. Blodget first clearly emphasized the fact that the regular diurnal (i. e., solar) control is dominant in the West, while changes "of what may be called the greater nonperiodic sort" distinguish the East. "Extreme contrasts, diversities, and transitions belong here (in the interior) to *place* or *locality;* in the East to *time.*" This is a significant statement. It emphasizes the importance of the regularity of the solar control, and of the part played by the topography in the West. In the East, *per contra*, the time of the arrival and departure of cyclone or anticyclone is the deciding factor.

The common designation for the temperature differences which occur during a day is the diurnal range.[37] The greatest daily ranges of temperature, resulting from the normal warming by day and cooling by night, occur over the western plateau province and in summer. Here, in July (chart 17), practically the whole area has average daily ranges over 30°, and much of it has ranges of over 35°. Differences of 50° between early morning and noon are common. Individual cases of a rise from near the freezing point to 80° and even to 90° are on record. Over the eastern province the daily ranges are considerably less. They decrease from about 30° over the Plains (July) to less than 20° over the Great Lakes, along the Atlantic and Pacific coasts, and over the Gulf province. On much of the immediate Atlantic, Gulf, and Pacific seacoast the ranges are under 15°. The daily temperature ranges of summer over the eastern interior are relatively small, considering the continental climate and the high temperatures. Hann has attributed this fact to the high humidity of summer, which gives an almost tropical character to the climate at that season—a climate marked by relatively small daily ranges of temperature.[38]

The average daily temperature ranges for January are shown in chart 16. On the whole, these ranges are smaller than in July, especially over the western Plateau province, where the diurnal control is least marked in midwinter.

The sudden, irregular temperature changes which occur under cyclonic and anticyclonic control, and are chiefly characteristic of the East, may be as great as those which are due to normal diurnal control in the West. Thus, a winter warm spell with southerly winds and a temperature in the neighborhood of 50° may be followed within 24 hours by a cold wave with zero temperatures over the northern tier of States. Remarkably sudden temperature changes also occur in connection with chinook winds along the eastern base of the Rocky Mountains. Or, in summer, during a hot wave, the advance of a cyclonic cloud sheet and the setting in of cool easterly winds on the Atlantic coast "breaks" the heat within a few hours, bringing welcome relief. Several different types of weather bring these "paroxysms of change" (Blodget).

Highest and lowest "record" temperatures.[39]—Great popular interest always attaches to the "record" highest and lowest temperatures. Obviously, the longer the period of observation, the higher and lower these absolute maxima and minima will be. Chart 18, which supersedes all the older charts of absolute minima, shows the lowest temperatures ever observed in the United States, and is based on the records of about 600 stations. The lowest readings of standard thermometers, under proper conditions of exposure (−60° and a few degrees below) have occurred over the northern Plains, the gateway through which cold waves from western Canada enter the United States. Temperatures low enough to freeze mercury (−40°) have been recorded as far south as western central Colorado, northeastern Nebraska, and central Minnesota and Wisconsin.

Minima below zero have been observed over a large part of the United States. Starting from the Atlantic coast at the latitude of southern Virginia, the line along which zero temperatures have been recorded runs southwest, at some distance inland from the ocean, to northwestern Florida; then roughly parallels the Gulf coast, crosses Texas north of latitude 30° N. then turns northwest across southwestern New Mexico and central Arizona, keeping at first east of, then along and finally crossing to the west of, the Sierra Nevada-Cascade Mountains. It ends in western Washington, but does not touch the actual Pacific coast. Zero has not been recorded on the Atlantic coast south of Chesapeake Bay, on the immediate Gulf coast, or in the valley of California. It is a striking fact that the absolute minima over the northern Plateau west of the Rocky Mountain barrier, and also those along the eastern base of this barrier, are distinctly higher than those over the northern

[37] When the difference between the mean temperatures of the warmest and coldest hours of the day is given it is known as the *periodic diurnal range*. When the difference between the mean daily maxima and the mean daily minima (determined from readings of the maximum and the minimum thermometers on individual days) is given, it is known as the *nonperiodic diurnal range*. The latter is the one usually given in climatic tables and discussions. It is determined much more easily, and for all practical purposes may be used instead of the periodic range. When hourly temperature data are available, the periodic range is easily worked out. (In connection with this, see Alexander McAdie: "Mean Temperatures and Their Corrections in the United States," 1891; tables of mean hourly temperatures for regular Weather Bureau stations for the five years 1891–95, in *Ann. Rept. Chief of Weather Bureau* for 1896–97, pp. 94–107: also short table of mean diurnal periodic ranges, based on McAdie's report, given by Hann in his Handbuch der Klimatologie, Vol. III, 3d ed., 1911, p. 363.

[38] J. Hann: Handbuch der Klimatologie, vol. 1, 3d ed., p. 362.

[39] Henry has given (*Bulletin Q*, Table II, pp. 88–92) the absolute maximum and minimum temperatures for selected stations, with year of occurrence, for the period 1871–1903. More recent and fuller data will be found in the regular monthly and annual summaries published by the Weather Bureau. For information about the available charts, reference may be made to R. DeC. Ward: Bibliographic Notes on the Temperature Charts of the United States. MO. WEATHER REV., 1921, 49: 277–280.

Plains, in spite of lower elevations in the latter district. The effect of the barrier is here clearly seen. During inversions of temperature, which characteristically accompany the occurrence of the lowest minima, elevated stations are often considerably warmer than those near by, on lowlands or in valleys.

Similarly, the advance of cold from the northern Plateau districts to the Pacific coast is prevented by the barrier of the Sierra Nevada-Cascades. Key West, Fla., is now the only regular Weather Bureau station at which no minimum temperature below freezing has been recorded. The north is not, however, under all conditions, colder than the south. There are cases, not by any means extremely rare, when the southern tier of States is temporarily having colder weather than those to the north.

There is a considerable tempering of the extreme cold to leeward of the Great Lakes, as is shown by the warping of the lines of equal absolute minima, as, e. g., along the southern shores of Lakes Erie and Ontario and along the eastern shore of Lake Michigan. During severe winter cold waves the lee shores of these Lakes may have temperatures 10°–20° or so higher than those observed at the same time on the opposite (windward) shores.[40] Alexander Winchell, by means of his lines of equal absolute minima, first showed in a striking way the moderating influence of the Great Lakes, especially of Lake Michigan, upon the winter temperatures in their vicinity.[41] As shown by Eshleman in a much later study, the absolute minimum temperatures at Grand Haven in winter (Nov.–Jan.) run higher by about 10° than those at Milwaukee, and by about 12°–16° (Oct.–Jan.) higher than those of a group of western inland stations on the same latitude.[42] "Whole weeks of zero weather occur in Wisconsin and Minnesota when the temperature at Grand Haven will not go below 15° or 20°." The Lake influence is clearly seen in the occurrence of an extended and important fruit belt, which reaches from the southwestern corner of the State along the eastern shore of Lake Michigan as far as Grand Traverse Bay.[43] The famous peach region of Michigan forms part of this same belt. The absolute maxima, as shown on the new chart (chart 19), are surprisingly uniform over the United States as a whole. The differences are slight, and the lines of equal absolute maxima show no such well-defined system as is the case with the minima. For purposes of broad generalization, and of easy memorizing, it is perhaps enough to say that extreme temperatures of over 100° have been observed over most of the United States. The exceptions are the immediate northern coasts of Atlantic and Pacific Oceans; portions of the Lake region; central and southern Florida, the Texas coast, northern New England, and the higher parts of the mountain areas. Over all these last-named districts, the readings are from somewhat under 95° to a little under 100°. The tempering influences of the Great Lakes are again seen in the deflection of the lines of equal absolute maxima. The values are roughly 10° less on the eastern than on the western shore of Lake Michigan. Grand Haven has summer maxima lower by 6°–7° than those of Milwaukee and by 10°–15° lower than those of the group of western continental stations.[44] "A difference of 10° to 20° in the maximum temperatures (at Grand Haven) compared with inland stations on warm days is a common occurrence." The highest readings for the country as a whole exceed 120° in southwestern Arizona; maxima over 115° occur over a larger district of northeastern California, southeastern Arizona, as well as in the valley of California. The "record maximum" is 134°, recorded at Greenland Ranch, on the edge of Death Valley (July 10, 1913.[45]) Owing to the small scale of the map, the high temperatures in Death Valley are not indicated. It should be added, however, that the excessively high maxima of the far Southwest are associated with relatively dry air, and are far less oppressive, and less physiologically dangerous, than the lower maxima in the moister air of the east.

The average lowest temperature of the year.—The average lowest temperature reading of the year (mean annual minimum) not only has a general popular interest, but is also important because of certain of its economic relations. The new chart of average annual minimum temperatures (chart 20) replaces a far less complete one published by van Bebber in 1893.[46] A thermometer reading below —30° is a normal winter occurrence over the northern Plains and northern Minnesota. Northern New York and northern New England have —25°. Temperatures below zero are to be expected on the coast as far south as southern New England, southern New York, and northern New Jersey. From this section the line of mean annual minimum of zero runs in a general southwesterly direction across Maryland, Kentucky, northern Tennessee, southern Illinois and Missouri, northern Arkansas, Oklahoma, and northern Texas into eastern New Mexico. Thence it turns west and northwest, following along the eastern slopes of the Pacific coast ranges, and ending in eastern Washington. The Gulf States have minima mostly between 10° and 20°, with over 20° over all of Florida and along the Texas coast. The tempering of the cold by latitude is thus clearly indicated. Topographic controls are seen in the positions of the lines over the western plateau and mountain districts, e. g., in Colorado, New Mexico and Arizona. The Rocky Mountains obviously act as an effective barrier against the penetration of extreme cold from the northern Plains into the Plateau districts. No cold of eastern intensity is indicated in any portion of the great district to the west of the Rocky Mountains. The Pacific coast is further protected by the Sierra Nevada-Cascade barrier against the invasion of low temperatures from the east. On the immediate Pacific coast, the mean annual minima are 20° in the north and 30° in the south.

The irregularities of the lines in the Lake region, especially in the case of Lake Michigan and of the lower peninsula of Michigan, and of the lee shores of Lakes Erie and Ontario, show a very obvious tempering effect of the Lake waters.[47] The mean monthly minima at Grand Haven, Mich., run about 4°–6° higher than those at Milwaukee Wis., during the winter, and 10° ± higher than those of a group of inland stations somewhat farther west.[48]

One of the striking, and one of the serious, climatic characteristics of the eastern United States, is the temporary and sudden penetration of very low minima far to the south, into latitudes where the winters are distinctly mild. This condition occurs in connection with

[40] See, e. g., E. T. Turner: The Climate of the State of New York. *Fifth Ann. Report Met. Bur. and Weather Service of the State of New York.* 8vo. Albany, 1894, p. 370.
[41] Alexander Winchell: The Isothermals of the Lake Region. *Proc. Amer. Assoc. Adv. Sci.*, vol. 19, 1870, pp. 106–117.
[42] Loc. cit.
[43] A. J. Henry, loc. cit., p. 556.
[44] C. H. Eshleman, loc. cit.

[45] G. H. Willson: The Hottest Region in the United States, MO. WEATHER REV., 1915 43: 278–280.
[46] Reproduced in *Atlas of Meteorology*, 1889, pl. 2.
[47] See, e. g., J. Hann: Atlas der Meteorologie, 1887, text, p. 5.
[48] C. H. Eshleman, loc. cit.

the advance of a cold wave from north and west. A general knowledge of the mean annual minimum temperatures is here essential to a full appreciation of the climatology of this area. Hann pointed out that the temperature at New Orleans falls each winter on the average nearly to 20°, while at Cairo in the same latitude, it reaches only a degree or so less than 40°. Yet both mean annual and mean January temperatures at these two cities are essentially the same.[49] And over half a century ago, Russell noted the fact that Savannah, Ga., has a mean winter temperature similar to that of May in London and of winter in Cadiz, which is 4½° of latitude farther north.[50] Yet the vegetation of southern Spain is quite different from that in North America because of the higher winter minima in the former country. In a case like this, vegetation becomes a better index than is the mean temperature. Oranges are liable to serious damage by frost over nearly all of the southern United States; not so in southern Spain. Cotton is replanted annually in the United States; not so in Spain. It is true that spells of considerable cold also invade low latitudes in eastern Asia, but there the mean winter temperatures are lower than in the eastern United States.

The mean annual maxima have much less human and economic significance than the mean annual minima.[51]

Other facts concerning annual and monthly maxima and minima.[52]—The differences which have been recorded between the highest and the lowest temperatures ever observed are worthy of note. These differences are of the order of 150° in the north-central districts of the interior; 125° in northern New England and the lower Lake region; less than 100° along the Gulf coast; about 50° at Key West; 120° in the Rocky Mountain and Plateau region generally; in the southwestern interior, 110°; less than 100° on the Pacific coast, with the exception of the Columbia River valley and the mountains.[53] During a single month, differences of the order of 100° may occur over the northern interior in winter, between the extreme cold of a cold wave and the high temperatures of a warm spell. Although these monthly ranges decrease rapidly to the south, they are greater than those of central Europe at least as far as latitude 40° N. (Hann.)

The differences in temperature from day to day.—There are two fundamental controls determining the differences in temperature from one day to the next. One is regular; the other, irregular. The first is the sun. Under the sun's control alone, each day should normally be a little warmer than the preceding during the warming half of the year, and a little cooler during the cooling half. The second is the cyclonic and anticyclonic control. This is irregular, varying with the temporary conditions of pressure distribution and the accompanying temperature, winds, clouds, and rain. The second of the two controls is by far the most important over most of the United States and most of the time, especially during the colder season. It brings marked and sudden temperature changes from day to day, completely upsetting the orderly seasonal advance and retreat. These day-to-day changes in temperature are of great importance in relation to human comfort and health. They markedly affect a wide range of man's activities. The conventional method of expressing such changes is to give, for each month, the average difference between the mean temperatures of successive days.[54] In a table compiled by Supan some years ago it appears that the interior of North America, including the northernmost parts of the United States, is one of the two centers of maximum diurnal variability in the Northern Hemisphere.[55]

Generalizing broadly, it may be stated that the mean diurnal variability in winter is of the order of about 10° in the northern central interior, and decreases from there in all directions, to about 2.5° on the north and 2° on the south Pacific coast; a little over 5° on the Gulf Coast, and about 3° in southern Florida.[56] The decrease from the interior to the Atlantic coast is relatively slight, because this leeward coast shares so largely in the continental conditions of the interior. The lines of equal variability follow the lines of absolute minimum temperatures reasonably closely, indicating a dependence of the large diurnal variability of winter upon the occurrence of cold waves. The mean diurnal variability in summer is usually about one-half of that in winter. It should be observed that the foregoing data refer to differences between the daily *mean* temperatures, and not to the total amount of rise or fall of temperature from day to day. Such irregular changes are of striking frequency and of large values, especially in the northern United States east of the Rocky Mountains in winter, reaching 50° or even more within 24 hours.

Several factors combine to bring about these rather remarkable irregular temperature changes in the eastern United States, viz, the rapid winter poleward temperature gradient; the presence of the warm Gulf of Mexico in the south, the Gulf Stream off the east coast, and the cold continent to the north; and the frequency, intensity, and rapid progression of cyclones and anticyclones. Under the control of the rapidly changing pressure gradients as HIGHS and LOWS pass by, the winds are constantly changing their direction. Thus, large masses of air, often moving at high velocities, are imported from districts of widely varying temperatures, now from the warm Gulf of Mexico; now from the cold plains of western Canada; now from the Atlantic Ocean on the east. Marked and sudden changes in temperature and in general weather conditions are therefore inevitable. Furthermore, winds not only control temperatures directly, by the actual importation of warm or of cold air, but also indirectly, by bringing clear skies and thus increasing the local production of cold by nocturnal radiation on quiet nights and the warming under sunshine by day, or by bringing clouds and rain and thus cutting off sunshine by day and checking terrestrial radiation by night.

Does the annual march of temperature show persistent irregularities?—There is a widespread popular belief in the recurrence, at about the same time every year, of longer or shorter periods of unseasonable cold or heat. Among these "spells" of weather the ones most commonly referred to in the United States are the "January thaw," a cold period about the middle of May, and the

[49] J. Hann: Atlas der Meteorologie, 1887, text, p. 5.

[50] Russell: North America, its Agriculture and Climate, Edinburgh, 1857. Quoted by J. Hann: Handbuch der Klimatologie, 3d ed., vol. 3, 1911, p. 364.

[51] No chart of mean annual maxima has been prepared since that of van Bebber, 1893.

[52] The complete numerical presentation of highest and lowest temperatures requires several columns in a standard climatic table (see, e. g., J. Hann: Handbook of Climatology, 2d ed., vol. 1, English translation by R. DeC. Ward, table on p. 33.)

[53] A. J. Henry, loc. cit, pp. 29–30. No map of the *mean annual extreme range* has been constructed since that of van Bebber, for the world (*Atlas of Meteorology*, Pl. 2). These ranges, also known as the *mean annual non-periodic ranges*, average about twice as large as the *mean annual periodic ranges* previously referred to, which are based on the differences between the mean temperatures of January and of July.

[54] *Mean diurnal variability of temperature*, i. e., the mean of the differences between successive daily means. Data regarding this factor have been worked out for comparatively few stations in the United States. See tables of "Average Daily Variability of Temperature" (for 18 selected stations), and of "Average Daily Variability of Temperature in Percentages, Washington, D. C., 1883–1903," in *Bulletin Q*, p. 33. Also *Ann. Rept. Chief of Weather Bureau for 1896–97*, p. 284.

[55] A. Supan: Grundzüge der Physischen Erdkunde, 3d ed. 1903, p. 99.

[56] See chart prepared by Gen. A. W. Greely, "Variability of average daily temperature in January," reproduced in F. Waldo's Elementary Meteorology, 1896. Fig. 101, pp. 330–332.

"Indian summer." Prof. Charles F. Marvin, Chief of the Weather Bureau, has recently investigated this question by making a study of the temperature records for several long-period stations in the northeastern United States, supplemented by 45-year records from Weather Bureau stations scattered over the country.[57] The conclusion reached is that the annual record of daily mean temperatures is a smooth curve, without secondary maxima or minima, or of perceptible points of inflection. Such marked irregularities as are described by the terms "January thaw" or "May freeze," neither persist, nor do they have a real existence. In cases where these or similar irregularities appear in the means, they are the effect of a single occurrence, or of a few accidentally recurrent unusual or extreme events, near or at the time in question. A study of the long-period temperature record s keptat New Bedford, Mass., between 1813 and 1905, was made by the late Waldo E. Forbes.[58] The object of this investigation was to discover evidence for or against the occurrence of a cold spell in New England about May 10 ("Ice Saints"). It appears that cold weather as well as hot may be expected on May 10, and hot weather as well as cold on May 7 or May 13. "It is nevertheless possible that when the pulsations of the weather are better understood, May 10 may prove to be a sort of node and may serve as a point of departure for the study of weather waves."[59]

ON THE DEPRESSIONS OBSERVED IN THE VALUES OF SOLAR RADIATION INTENSITY.

551.590.2 : 551.5

By LADISLAS GORCZYŃSKI.

[Translated by W. W. Reed, from *Bollettino Bimensuale, Soc. Met'l. Ital.*, Apr.-June, 1921, pp. 25-28.]

While very warm or rainy summers and very mild or cold winters come directly to general notice, depressions, and in general all the abnormal variations in the values of the intensity of solar radiation measured at the surface of the earth, do not manifest themselves immediately to the eyes of observers and require a scientific demonstration by special instruments known as pyrheliometers and actinometers.

Yet the study of these depressions, or rather of all the variations that appear in the values of solar radiation observed at the surface of the earth, has an importance all the greater since it is indeed the solar energy that is, in the last analysis, the *spiritus movens* in all the atmospheric movements observed on the earth. In order to find an explanation of the very complicated variations of temperature of the air and of precipitation it is necessary to begin with the study of solar radiation.

For this reason, we believe it useful to discuss briefly the two great depressions in solar radiation that have occurred since the beginning of the twentieth century; these are the depressions of 1902 and 1913, which we have demonstrated from pyrheliometric and actinometric measurements made at Warsaw without interruption since the close of 1900.

It is important to add that these depressions observed at Warsaw have been discovered in the series of measurements made at other observatories in Europe and in America;[1] these depressions have consequently a world-wide character.

To establish the existence of these depressions in the values of solar radiation observed at Warsaw let us take the monthly maxima (Max. Q) of the intensity of solar radiation. Granted that radiation is subjected in the earth's atmosphere to influences that always tend to diminish it, the conclusion is easily reached that it is especially the maximum values in the diurnal and annual periods that are the most characteristic. Besides the conclusions reached by examination of the monthly maximum values of radiation are confirmed by the consideration of the monthly mean values and also by the observation of the duration of insolation (in hours) and by the calculation of the totals of insolation (in kg. cal.) to one sq. cm. of the normal horizontal surface.

Being unable, in the present paper, to enter into the details of the matter, let us note that the results of the observations and calculations are found in the following publications by the author:

1. Valeurs pyrhéliométriques et les sommes d'insolation à Varsovie pendant la période 1901-1913. Warsaw, 1914. (*Publications de la Société des Sciences de Varsovie.*)
2. Sur les dépressions en 1912 et 1903 dans les valeurs de l'intensité du rayonnement solaire. Warsaw, 1914. (*Comptes Rendus de la Société des Sciences de Varsovie.*)

In Table 1 are presented the departures of the monthly maximum values of solar radiation at Warsaw during the period from 1901 to 1918. The departures (relative to the means for 1901-1913 and 1914-1918) are calculated in gr. cal. per sq. cm. per minute. The departures for the five years, 1914-1918, are given separately because of change in the place of observation in the first half of 1914, when the apparatus (Michelson actinometer and Ångström pyrheliometer) were transferred from the building of the Musée d'Industrie et d'Agriculture, situated more in the center of the city, to the building of the Société des Sciences of Warsaw, about 2 km. distant from the former.

Although, especially on account of the smoke of the city, both points of observation are far from favorable for measurements of solar radiation, it is of consequence to note that the latter place seems to be the better and gives higher values.

NOTE.—The values for 1901-1913 were calculated and published by the author (loc. cit.); the values for 1914-1918 were calculated by the observer, E. Stenz, but have not been published.

In the months for which departures are not given, actinometric measurements could not be effected.

Table 1 shows immediately that certain periods present depressions. In calculating the values of max. Q (for m, 1.5 atm. and f, 7 mm.) there is obtained the following

[57] Charles F. Marvin: Are there Persistent Irregularities in the Annual March of Temperature? MO. WEATHER REV., 1919, 47: 544-555. The same number of the REVIEW also contains a useful *annotated bibliography of this subject* (pp. 555-565), by C. F. Talman.

[1] See Kimball, Herbert H.: Volcanic eruptions and solar radiation intensities. MO. WEATHER REV., Aug. 1918: 46:355-356.

[58] Waldo E. Forbes: Ice Saints, *Am. Astron. Observatory Harv. Coll.*, vol. 83, pt. 1 1917, pp. 53-59.

[59] An early discussion of this subject may be found in C. A. Schott: Tables, Distribution and Variations of the Atmospheric Temperature in the United States and some Adjacent Parts of South America. *Smithson. Contr. to Knowl.* 277. Washington, D. C. 1876. pp. 192-194.